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ORIGINAL ARTICLES.

On Certain Xenoliths associated with the Contaminated Rocks of the Huntly Mass, Aberdeenshire.

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I. Introduction.

CONTAMINATED igneous rocks [1, pp. 177–83; 2, pp. 446–86; 3, pp. 128–46][1] are those resulting from the solidification of a magma which has been modified by reaction with xenoliths, usually of sedimentary origin. The Younger Gabbro masses of North-East Scotland provide what are probably the best examples of this phenomenon yet known, and their investigation will doubtless throw some light upon current petrogenetic theory.

I have suggested [2, pp. 479–84; 3, p. 140] that the process of this contamination depends upon a reciprocal reaction between initial gabbro magma and argillaceous xenoliths, resulting in a concentration of acidic oxides in the magma and of basic oxides in the xenoliths. Reciprocal reaction is the obvious, and, to me, the only possible explanation of contamination, but I have hitherto not been able to prove the modification of the xenolithic part of the complex as completely as that of the magmatic part. Criticism directed to this shortcoming was, of course, quite justified, since there were only inadequate accounts of xenoliths which would have met that criticism. A detailed study of the xenoliths associated with the contaminated rocks was therefore undertaken. It is the purpose of this paper to give the results of a petrographic and chemical investigation of the xenoliths from two localities of contaminated rocks in the Huntly Gabbro Mass, Aberdeenshire.

II. The Basic Xenoliths.

Occurrence.

The Huntly Igneous Mass [3, pp. 104–16; 4, pp. 266–93] in Aberdeenshire has an area of nearly 50 square miles. It is formed mainly of gabbro and norite which in many localities have been contaminated with sedimentary material to produce cordierite-norites and allied rock-types, first described by Mr. W. R. Watt. Where these contaminated gabbros occur, xenoliths of sedimentary origin are abundant, at some localities sufficiently so to impart a conglomeratic aspect to weathered surfaces of the complex.

[1] Figures within square brackets refer to the Bibliography, p. 443.

At two easily accessible places in the Huntly Mass, such complexes are especially well seen. I have already briefly described the occurrences [3, pp. 130–3]. The first locality is in the south bank of the River Deveron, 250 yards east of the Castle Bridge, leading from Huntly to Huntly Lodge. My earlier description reads: "The igneous rock is so full of rounded phyllite fragments that, on weathered surfaces, it resembles a coarse conglomerate" [3, p. 130]. A diagram of a rock-face at this locality is given in Fig. 1. The

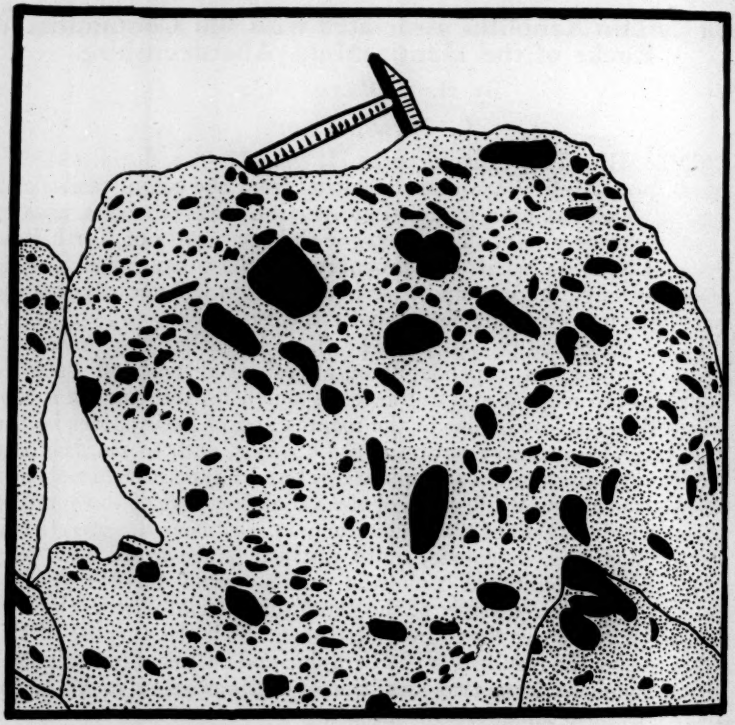

FIG. 1.—Diagram of a rock-face, Castle Bridge, River Deveron, Huntly. Solid black are sedimentary xenoliths, lying in a matrix (stippled) of garnetiferous cordierite-norite.

second locality is at Hill of Kinnoir, north-west of Loanend, and 3 miles north-north-east of Huntly. I have already said: "A conglomeratic rock, seen in an old quarry on the northern slope, is a contaminated norite crowded with partly digested blocks and rounded 'pebbles' of hornfelsed sediments" [3, p. 131]. Brief descriptions of half a dozen xenoliths, together with a chemical analysis of one, were given in the Memoir cited.

Last year (1923) I revisited these localities and collected a hundred or so xenoliths, a proportion of which I have since sliced and

examined; I am able to give here, too, a second chemical analysis of a typical xenolith from these contaminated-rock complexes.

The xenoliths occur in a matrix of coarse garnetiferous contaminated rock, from which, when weathered, they can be easily extracted. There are a few xenoliths of a whitish quartzite, but by far the dominant type is a blue compact hornfels. Certain large blue xenoliths (up to 6 or 7 inches in length) are relatively lowly altered slaty rocks, but the smaller xenoliths are of dense crystalline hornfels. These small xenoliths are most common. They are on an average a half to 1 inch across, often flattened and always well rounded; when broken through they exhibit a zoning parallel to the surface of the xenolith, which is emphasized on weathering. There are obtainable all transitions between the large slaty xenoliths and these smaller ones. So far as externals go, it seems justifiable to conclude that all these blue xenoliths were of one rock-type, probably slaty, and that the smaller the xenolith the more intense is the alteration to which it has been subjected.

Petrography.

Examination of slices of the small and most abundant xenoliths shows that they are of a uniform type characterized by the marked dominance of clinopyroxene, hypersthene, and hornblende. They are basic hornfelses. The chief mineral is augite; hornblende and hypersthene are less abundant, whilst iron-oxide, sphene, quartz, basic plagioclase, and biotite are still less common.

The augite is colourless or pale greenish, and forms grains, small plates or large, sieved, rather shapeless, plates packed close together; it is occasionally intergrown with hornblende. The hornblende forms large sieved plates, repeatedly twinned; it is usually colourless in slice, but at times has a slight brownish or greenish tint; it is occasionally wedged between pyroxene crystals and then shows a peculiar limpid appearance. The hypersthene is either granular or in large sieved porphyroblasts; the usual pleochroism in pale pink and green tints is seen; its sign is negative. Black iron-oxide is abundant in grains and streaks of all sizes. Sphene forms shapeless grains up to 0·5 mm. across, and is occasionally fairly abundant; it is pleochroic from colourless to rich red. Quartz occurs sometimes as scattered large grains, but usually it is associated with plagioclase in a very fine mosaic, constituent grains of which have an average diameter of 0·1–0·2 mm. Plagioclase, a labradorite-bytownite, forms, in addition to the small grains in the quartz-felspar mosaic, rare plates of some size between the pyroxene crystals. Biotite has the yellow to red pleochroism of hornfels-biotite, and occurs either as small plates or as large sieved plates associated with hypersthene; it is sometimes collected in biotite-rich bands.

The proportion of the three chief mafic minerals, augite, hornblende, and hypersthene, varies to a certain extent in different xenoliths, and, as shown immediately, in different zones of the

same xenolith, but always these mafic minerals are markedly dominant—in some xenoliths practically no other mineral is present, and in all those being considered here it is probable that minerals other than these three never amount to more than an eighth of the rock.

The xenolith most commonly met with is conspicuously zoned (see Fig. 2). The zones follow the present surfaces of the xenoliths and often run across any original stratification differences that are recognizable. The zones are from the centre outwards :—

(*a*) Augitic central zone (main part of xenolith).
(*b*) Narrow intermediate zone, hornblendic.
(*c*) Marginal zone, hypersthenic.

The central part of the zoned xenoliths shows in many cases 95 per cent of augite, in aggregated grains, packed small prisms, or very large, closely packed, rather shapeless, plates, usually elongated in the prism-zone and often exhibiting sieved structure due to the inclusion of quartz and felspar pellets ; these pyroxene plates may reach a size of 2 mm. In addition to the pyroxene, there occur scattered shapeless grains of sphene, a few patches of quartz-felspar mosaic, and rare poikiloblastic plates of basic plagioclase. In this zone, too, there are often seen a few hornblende plates wedged between the pyroxenes, and a plate or two of hornfels-biotite. Black iron-oxide is dusted throughout the zone.

The intermediate zone is characterized by dominant hornblende and is usually very narrow. It is formed of lamellar or platy hornblende, arranged in most cases rudely perpendicular to the margin of the internal zone, together with considerable quartz-felspar mosaic and the ubiquitous iron-oxide granules.

The external zone is characterized by hypersthene, in grains, collections of grains, or large porphyroblasts, so well sieved that the hypersthene substance forms, as it were, a cement to quartz and felspar grains. Quartz-felspar mosaic is abundant and sometimes rather coarse and in addition there are many iron-oxide streaks and often large red hornfels-biotites. This zone is rather sharply defined against the adjacent contaminated rock matrix, and the junction is occasionally marked by a band of biotite plates laid against the boundary.

These three zones are the rule for the smaller xenoliths, but they may be concealed by the direction of the slice, by the absence of the intermediate hornblendic zone, or by the large size of the central augitic part. In several cases, however, it is possible to trace the three zones continuously within the xenolith. In some examples, too, there are two or more augitic kernels, each surrounded by the hornblendic zone and the whole bordered by the hypersthene zone. In one slice, the hypersthenic and hornblendic zones, as cut in the section, run clean across the relics of the original sedimentary banding. In other xenoliths, the zoning is replaced by a patchiness,

in which parts of the slice are rich in hornblende, parts in pyroxene, and parts in red hornfels-biotite in tiny flakes.

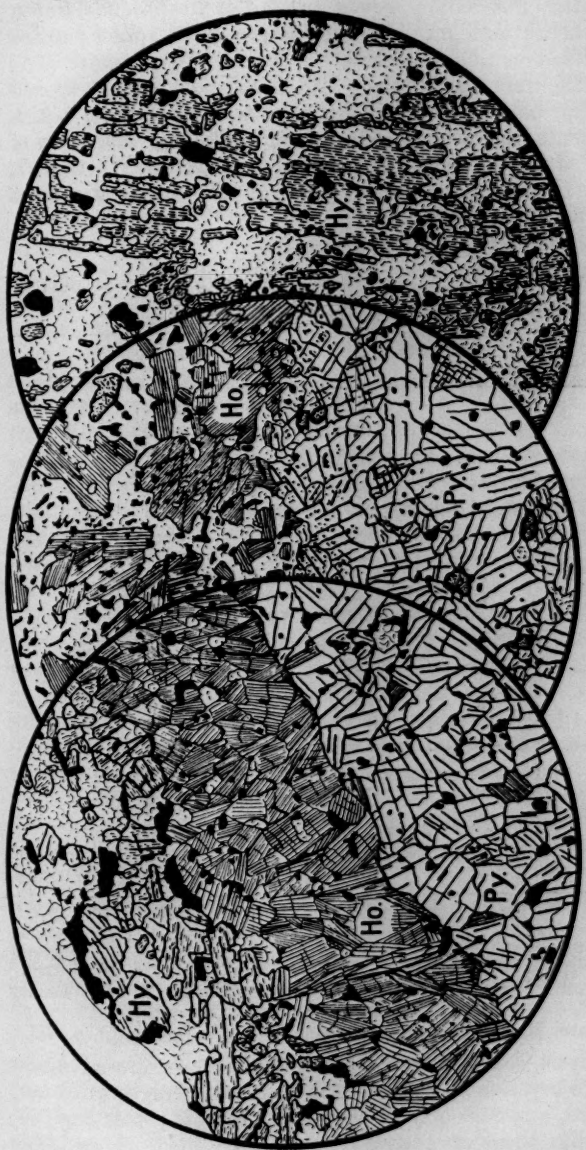

FIG. 2.—Zoned xenoliths, Hill of Kinnoir, Huntly.

A.—Internal zone of pyroxene (Py.), followed outwards by a zone mainly of hornblende (Ho.), and this by a zone of hypersthene (Hy.), with a fine quartz-felspar mosaic. Solid black is iron-oxide.

B.—Lower half of the field is formed of pyroxene (Py.), upper half of hornblende (Ho.) and quartz-felspar mosaic. Solid black is iron-oxide. Few grains of sphene (stippled) are seen.

C.—The outer, hypersthenic, zone of a zoned xenolith. Sieved hypersthene (Hy.) in a quartz-felspar mosaic. Solid black is iron-oxide.

We may say with confidence that these zones are developed on the best scale in the smaller xenoliths. The larger xenoliths, which in the

field were considered to be definitely of slate, are found in slice to be finer-grained than the more basic xenoliths. They are composed of very abundant, but small, sieved prisms of hornblende, much iron-oxide in shreds and grains, irregular grains of sphene, a few specks of hornfels-biotite and a minute quartz-felspar mosaic.

I may recall the xenolith from the Hill of Kinnoir already figured [3, p. 132]. This basic zoned xenolith has a central part, which possibly represents the original laminated sediment, made up of quartz grains and chloritic and sericitic material; this is surrounded by the internal augitic zone of the small xenoliths already described.

Chemical Composition.

There are now available analyses of two basic xenoliths associated with the contaminated rocks of the Huntly Mass.

	I.	II.	III.
SiO_2	54·58	59·98	58·47
TiO_2	trace	0·64	1·30
Al_2O_3	8·96	13·52	18·27
Fe_2O_3	0·66	1·13	1·66
Cr_2O_3	nt. fd.	nt. fd.	—
V_2O_3	—	nt. fd.	—
FeO	5·55	3·50	6·49
MnO	1·28	0·22	0·25
(CoNi)O	nt. fd.	nt. fd.	(?) trace
BaO	—	0·03	0·05
CaO	17·55	9·11	0·78
MgO	10·04	6·28	2·64
K_2O	trace	1·50	2·84
Na_2O	trace	0·94	2·46
Li_2O	—	trace	nt. fd.
H_2O at 105°	0·30	0·55	0·09
H_2O above 105°	0·65	0·67	3·37
P_2O_5	0·22	0·13	0·15
FeS_2	—	0·18	0·60
Fe_7S_8	—	1·70	0·72
CO_2	nt. fd.	trace	0·08
S	0·06	—	—
SO_3	trace	—	—
Totals	99·85	100·08	100·22

I. Basic Xenolith, Hill of Kinnoir, Huntly. Anal., W. H. Herdsman.
II. Basic Xenolith, Castle Bridge, Huntly. Anal., E. G. Radley [3, p. 138].
III. Macduff Slate, Macduff, Banffshire. Anal., E. G. Radley [3, p. 64].

The first analysis, I, is of a typical small xenolith, composed almost entirely of large crystals of augite, with scarce sphene, hornblende, iron-oxide grains, and rare quartz-plagioclase mosaic; this analysis, as it stands, is like those of many augites.

The second analysis, II, is of a hornblendic xenolith and represents the larger, or less completely altered, type.

The main part (the central augitic zone) has a composition represented by the analysis I above ; the bordering narrow hornblendic and hypersthenic zones will not differ markedly from this, but such differences as they do exhibit tend to bring them nearer to the composition of the adjacent contaminated rocks. From centre to margin of a zoned xenolith it is probable, reckoning from analysed augites, hornblendes, hypersthenes, and bytownites, that there is an increase in alkalies and alumina and a definite decrease in lime ; magnesia perhaps is steady, whilst total iron-oxides will not vary much.

Original Rock of the Basic Xenoliths.

There is good field-evidence that all the blue hornfels xenoliths associated with the contaminated rocks of the Huntly Mass were derived from slaty rocks. Thus, the large blue xenoliths are recognizably altered slates, and a passage in size and correlated degree of basification is found from the large xenoliths down to the small pyroxene-xenoliths. Further, the well-developed examples of gabbro contamination described by Mr. W. R. Watt and by myself from North-East Scotland, and also the exactly similar contaminated gabbros of France [5] and Minnesota [6] are all intimately associated with argillaceous terranes, and the proved differences between the initial igneous magmas and the contaminated derivatives (see p. 441) demands contamination with rocks capable of supplying abundant alumina and alkalies. Moreover, the composition-zoning of the smaller xenoliths, and the agreement between this zoning and the margins of the xenoliths as now found, point to an action subsequent to incorporation in the magma. If the small xenoliths be considered to have their composition substantially unaltered then they must have been derived from dolomitic or chloritic marls, possibly somewhat like the Garron Point actinolite-schist of Banffshire [3, p. 64]. Apart altogether from the absence of such rocks adjacent to these contaminated gabbro complexes, and apart from the points already set forth in this paragraph, it seems extremely unlikely that only the smallest xenoliths should be of this rock, whilst the larger xenoliths should be passages between such rocks and argillaceous rocks.

So remarkable is the chemical and mineralogical composition of the small basic xenoliths, that it might be suggested that they are not of sedimentary origin at all, but are cognate enclaves. Reasons against this interpretation are : (1) they are transitional from larger slaty xenoliths ; (2) they are associated with contaminated rocks ; (3) they have not been found in the fifty square miles of uncontaminated Huntly gabbro ; (4) they are zoned ; (5) they have a quartz-felspar mosaic of hornfels type ; (6) all their mafic constituents have typical hornfels sieve-structure ; (7) red sphene is abundant in them, but is unknown in the Huntly gabbro.

I therefore conclude—and this conclusion will be found to be strengthened by the discussion of the magmatic part of the con-

tamination-process given on p. 441—that the small basic xenoliths were originally of argillaceous rocks, and have been chemically modified during the contamination-process.

As the original rock of these xenoliths, the Macduff Slate of Banffshire may be taken (analysis III), since it is a typical and widespread argillaceous rock of North-East Scotland, and since it, or a more intensely regionally metamorphosed type, forms the main parts of the roofs of the great gabbro masses of this quarter.

On making a comparison between the two analyses of basic xenoliths and that of the Macduff Slate, two features emerge. In the first place it will be noted that the main differences between the two basic xenoliths, on the one hand, and the Macduff Slate on the other, are of the same kind, but that the hornblendic xenolith stands intermediate between the pyroxenic xenolith and the slate. In the second place, to produce the basic xenolith from the slate it is necessary to call into operation the following :—

Xenolithic Change. { (1) Abstraction of alumina, potash, and soda. (2) Introduction of lime and magnesia.

Basic hornfelses, which appear closely to resemble the Scottish examples, occur adjacent to the Bushveld Complex of South Africa, as described mainly by Mr. A. L. Hall [7, p. 5, pl. ii, fig. 1 ; 8, pp. 122, 126–9, 133 ; 9]. The huge Bushveld intrusion is in contact mainly with Pretoria Shales and the basic hornfelses are found either as xenoliths within the norite of the complex, or immediately against the norite. Further, the great intrusive sheets of the Bushveld region are flanked at their immediate contacts with the shales of the Pretoria Series by narrow zones of hornblende and pyroxene hornfelses. Such basic hornfelses are repeatedly mentioned by Mr. Hall, but in no case does he consider that they were derived from any other rock than shale. Moreover, he and Mr. C. Gardthausen [9, p. 78] explain their formation by an " interchange or transference of material consisting essentially in a removal of alumina and addition of magnesia and lime ". Again, Mr. Hall states [8, p. 133] : " It is, however, clear that the presence of basic rocks [of the Complex] along the margin does produce a purely local modification in the metamorphism, as seen in the occasional development of amphibole and pyroxene hornfels. This suggests a certain amount of transference of material, but such phenomena can naturally not extend far into the sedimentary floor . . ."

Finally, I have described similar basic hornfelses immediately adjacent to the olivine-norite of the Insch Mass [3, p. 161], and this mass is visibly roofed with Macduff Slate. It would be too great a coincidence that in all these cases great argillaceous terranes should contain original lime or magnesia-rich members only at their immediate contacts with gabbro sheets.

There is a very good case, therefore, for considering that the original rock of the basic xenoliths of the Huntly Mass was

argillaceous, and that it has been modified by the abstraction of alumina and alkalies and the addition of lime and magnesia.

III. Contaminated Rocks Associated with the Basic Xenoliths.

Contaminated derivatives of gabbro, by their mode of origin, are liable to great variations ; in the field they vary in the same exposure, and in both hand-specimen and slice they show a general patchiness. The selection of only a few specimens for analysis would, at first sight, destroy any chance there might have been of similarities emerging from the variety. Nevertheless, there are certain striking regularities about these contaminated rocks which cannot be over-emphasized, and these regularities are found not only in the contaminated rocks of North-East Scotland, but also in those described by Professor Lacroix [5] from Le Pallet, Loire-Inférieure, and by Professor A. N. Winchell [6] from Snowbank Lake, Minnesota. I have already compared [2, pp. 479–81] the thirteen analyses of contaminated gabbros with their initial magmas. Concerning the chief oxides, I showed that " Silica is mainly increased in the contaminated magmas ; alumina (with one exception) increases, and sometimes markedly ; there is a general rise in ferrous oxide, but of no great magnitude in any case ; lime is always much less ; magnesia, with one exception, is much less too ; potash in the majority of cases is increased ; soda is rather indefinite, but seems on the whole to increase . . ."

In other words, to produce the contaminated gabbros from their initial gabbro magmas, it is necessary to bring about the following :—

Magmatic Change { (1) Introduction of alumina, potash, and soda.
(2) Abstraction of lime and magnesia.

The contaminated magmatic rocks associated with the basic xenoliths of Hill of Kinnoir and Huntly Castle have already been described in detail by me [3, pp. 130–3]. They are coarse and variable rocks composed of intermediate and basic plagioclases, cordierite, quartz, spinel, hypersthene, biotite, garnet, iron-oxide, and sillimanite. The great gabbro or norite of the Huntly Mass is taken to be the initial magma upon which contamination has operated ; it consists [3, pp. 108–9] of acid bytownite and hypersthene, with monoclinic pyroxene, olivine, hornblende, biotite, and the usual accessories.

IV. The Reciprocal Reaction.

A comparison of what I have called the Xenolithic Change with the Magmatic Change shows at once that the one is the complement of the other. Those constituents which the initial magma loses on contamination are found in the xenoliths, and those that the initial sediment loses on conversion into a basic hornfels are found in the magma. Further, that the two changes do balance is additional evidence of the argillaceous nature of the original rock of the xenoliths, for in the contamination process there can be no absolute loss of material.

I have already given a chemical analysis of a contaminated rock from Castle Bridge, Huntly [3, p. 138]. It would be rash to expect a detailed reversal of the differences between this rock and its initial magma on the one hand, and between the initial sediment and the analysed basic xenolith on the other, since both components of the complex are variable. Nevertheless, as I have pointed out, the total amounts of lime, magnesia, and potash of the two initial rocks approximately equal the total amounts of the same oxides of the two resultant rocks [2, p. 481 ; 3, p. 140].

Reciprocal reaction is the *modus operandi* of the contamination of gabbros ; my reason for discussing it at some length is twofold. First, I had indicated, rather than proved, that the original sediment of the basic xenoliths was slate, and second, I had, at Arnage, analysed only a very large xenolith which did not represent the final stage of the process of basification.

In the passage of the argillaceous xenoliths into basic xenoliths, it is probable that the intermediate forms are represented by cordierite-spinel-rocks and cordierite-garnet-hornfelses. Xenoliths of the latter type are found abundantly in the Huntly Mass associated with contaminated gabbros, but it should be noted that these xenoliths are of huge dimensions. I have not yet re-examined these occurrences.

In summary, at two localities of contaminated rocks in the Huntly Mass certain xenoliths, originally argillaceous, have undergone a chemical change which is the reverse of that undergone by the initial gabbro magma of the Mass, and I have thereby supported my former conclusion that :—

" The contamination-process depends upon *reciprocal reaction* between the gabbro magma and argillaceous xenoliths ; the magma becomes more acid, and xenoliths more basic."

V. Gravitative Cleansing.

I may now discuss one theoretical development of the reciprocal reaction scheme, namely gravitative cleansing.

Let a thick sheet of gabbro be intruded into an argillaceous terrane and let a xenolithic zone be formed at the top of the sheet. In this xenolithic or contaminated zone reciprocal reaction between initial gabbro magma and argillaceous xenoliths takes place. We may take up the consideration of certain physical effects of the chemical changes occurring in the contaminated zone. It can at once be stated that as a result of the reciprocal reaction outlined above, the specific gravity of the magmatic part of the zone becomes progressively less, whilst that of the xenoliths becomes progressively greater. Blocks of mica-schist, say, would remain suspended or gradually sink in the gabbro magma, but, once reciprocal reaction has begun, this nice balance is disturbed, both by the magma becoming lighter and the xenoliths heavier. As contamination proceeds, the basified xenoliths sink more quickly. It is conceivable, then, that the

contaminated zone might be freed of xenoliths by this *gravitative cleansing* and a homogeneous upper part of the postulated gabbro-sheet be formed, markedly different from the initial magma.

If the basified xenoliths pass out of the contaminated upper zone they must reach the underlying unmodified gabbro-sheet; they can either traverse this sheet without modifying it in any way, or they can react with the magma of the sheet. In the first, a most improbable case, there would be formed a floor-body of ultrabasic rock, probably pyroxenite. In the second case, the gabbro would be enriched in lime and magnesia, with the formation of gabbros or norites rich in anorthite or hypersthene or pyroxene. It will be noted that I suppose the initial gabbro magma to part with lime and magnesia in the upper zone and to absorb the same oxides lower down. There is obviously a temperature difference which may play a part in this connexion, but the main difference is that the xenoliths presented to the magma in the two cases are quite unlike. In the contaminated zone the initial xenoliths are rich in alumina and potash, in the lower zone they are rich in lime and magnesia.

Dr. N. L. Bowen [10, p. 556] in his study of the behaviour of inclusions in igneous magmas, says :—

" Localized masses in process of reaction with the general mass may move, say in response to gravity, and their accumulation may give rise to bodies rich in minerals formed during the reaction."

Dr. Bowen would explain certain of the peridotitic and pyroxenitic differentiates of the intrusive masses of the eastern United States, together with some corundum deposits associated with these, to some such process of sinking of xenoliths after reaction with the initial magma has taken place.

In the supposed sheet, therefore, there would be produced a noritic or magnesia-lime-rich bottom-part and a granitic or alumina-alkali-rich upper part. The great differentiated sheets which show granite and norite—those of Sudbury, the Bushveld, etc.—may be worth considering by those familiar with these sheets, from the standpoint of reciprocal reaction with the roof and subsequent gravitative cleansing. I have suggested the same scheme to explain the granitic contaminated rock of Ardlethen type and the magnesia-rich norite of the Arnage Mass in the Buchan district of Aberdeenshire [3, p. 140 ; 11, pp. 63–4 ; 12, pp. 268–9].

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Pedology[1] as a Branch of Geology.

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Introductory.
Constitution of the Soil.
The Soil a Colloidal System.
Saturated and Unsaturated Soils.
The Pedogenic Processes.
Classification.
Principles of Classification.
Mature and Immature Soils.
Main Climatological Types.
Laterites and Lateritoids.
Podzols.
Black Earths and their Related Types.
Peats and their Related Types.
Saline and Alkaline Soils.
Soil Surveys.

Introductory.

TO the geologist the soil is an inconvenient mantle hiding the more important material which he wishes to study. Even the drift geologist, who is more particularly interested in superficial deposits, generally dismisses the soil as lying above his zone of interest. Yet the processes which go on in the soil horizons[2] have an importance apart from their significance in practical agriculture. The study of soils has, perhaps, suffered from its close relationship to practical affairs, for it has naturally been left to the agricultural chemist, who has been obliged to approach it with an applied bias. We have in our own country scarcely any research in which the material is treated from a purely scientific point of view and studied in the same way as rocks have been studied by geologists.

[1] The writer ventures to hope that this convenient term (Gr. πέδον = soil or earth) will be more generally used to describe the scientific study of soils. There seems to be no satisfactory alternative.

[2] i.e. the soil and subsoil down to the level at which the parent material of the soil is reached. The soil horizons would be included in Van Hise's "zone of weathering".

Constitution of the Soil.

No view of the processes of rock weathering can be complete without some understanding of the constitution of the soil and of the changes which take place in it. From a broad point of view the wearing point of rocks is actually in the soil horizons. In the cycle of change from rock to rock through weathering, transport, and consolidation, the soil is an important phase and as such is worthy of more attention from geologists.

The Soil a Colloidal System.

The study of colloids, which began with Graham and received further impetus from the work of Van Bemmelen, is of the first importance for pedology. The soil is a colloidal system, and many of the most important changes which take place therein can only be understood in the light of colloidal chemistry and physics. The most characteristic constituents of soils are colloidal organic matter and colloidal clay. The presence of these materials in soil distinguishes it from mere finely divided rock material. To the geologist the colloidal clay is of particular interest as a product of the chemical weathering of silicates. It occurs in association with colloidal organic matter as a gel-coating on the surface of more or less decomposed mineral particles. It is improbable that any sharp demarcation exists between unweathered particles and colloidal clay, and any separation of this gel-coating by mechanical means is necessarily incomplete. Experiments in this direction are, however, in progress in the Bureau of Soils at Washington. It is probable that even in heavy clays, the colloidal material only forms a fraction of the total material present; but, existing as a coating on the surface of non-colloidal particles, it gives characteristic properties to the soil or clay in which it occurs.

In the older literature on clay [1] it is generally assumed that the essential ingredient is kaolin or kaolinite. This view is scarcely tenable, amongst other reasons because typical kaolin or china clay lacks one of the most characteristic properties of clays, namely plasticity. That kaolinite is associated with clays is by no means improbable, and it may possibly be formed in the soil along with zeolitic minerals as a secondary product from colloidal clay. Colloidal clay would appear to be of the nature of an "adsorption

[1] It is perhaps necessary to direct the reader's attention to the different senses in which the term clay is used. Firstly, there is the *clay complex*, a colloidal substance which confers on natural clays and soils plasticity and other characteristic properties. Secondly, there is clay as the finest fraction isolated in mechanical analysis and defined, according to the convention in use in this country, as particles of diameter less than ·002 mm. Lastly, there is clay as a natural substance, either soil, subsoil, or geological formation. Even the heaviest of clays always contain appreciable proportions of relatively coarse particles. The writer has never found more than 65 per cent of clay, as shown by mechanical analysis, in any natural clay. And of this clay isolated by mechanical analysis only a small proportion is colloidal clay.

compound "[1] of indefinite composition containing silicic acid, and the hydrated oxides of iron and aluminium. Iron oxide is almost invariably associated with aluminium oxide and appears to fulfil a similar rôle in the clay complex.

The clay complex or "weathering complex", as it has been called by Van Bemmelen, is in all probability formed by the mutual precipitation of electro-positive colloidal solutions of iron and aluminium oxides and electro-negative colloidal solutions of silicic acid. These colloidal solutions may be presumed to originate from the hydrolysis of silicate minerals. With the weathering complex are associated the oxides of calcium, magnesium, potassium, and sodium. The alkali and alkaline earth hydroxides are liberated in the process of silicate hydrolysis, but by reason of their greater solubility, particularly in water containing carbon dioxide, are largely removed by percolating waters. The hydrolysis of silicates and the production of the weathering complex from the products of hydrolysis is a secular process. Attempts to imitate it in the laboratory have hitherto been unsuccessful, although the first stage of hydrolysis, indicated by the development of an alkaline reaction, was recognized many years ago by Daubrée and others.

Owing to the difficulty of isolating the clay complex unchanged it is not possible to give reliable figures for its chemical composition, but it is probable that it does not differ greatly in gross chemical composition from typical heavy clays. The clay fractions from a number of soils derived from Palaeozoic rocks examined by the writer contained from 42 to 49 per cent of silica and from 41 to 51 per cent of the sesquioxides. Methods are known for the estimation of the proportions of adsorbed alkali and alkaline earth bases in soils and clays.

Saturated and Unsaturated Soils.

The soil chemist distinguishes between adsorptively saturated and adsorptively unsaturated soils. Where excess of calcium carbonate is present, as in many fertile soils, the adsorptive capacity of the clay-organic matter complex is saturated, principally with calcium. In many soils of humid climates, however, there is considerable removal of adsorbed bases by leaching and this results, in the absence of calcium carbonate, in a desaturation of the soil or clay, which thereby acquires latent acid properties. Such soils, when brought into contact with solutions of neutral salts such as potassium chloride, take up the positive metallic ion, in this case potassium, giving up hydrogen ions to the solution, whereby an acid reaction is

[1] There is considerable evidence for postulating the existence of such "adsorption compounds" in nature. In ordinary chemical compounds chemical combination takes place between separate atoms or molecules. In adsorption compounds it may be conceived that one or more of the constituents consist of molecules which form the bounding surface of molecular aggregates whose interior molecules do not enter into combination. This conception is on the whole more satisfactory than regarding such substances simply as very intimate mixtures.

produced. In such cases a certain amount of iron and aluminium is found in solution, having been dissolved out from the clay complex.

The degree of saturation of their adsorptive capacity and the nature of the bases with which this capacity is saturated have an important bearing on the properties of soils. Highly unsaturated soils in humid climates are of inferior fertility and require dressings of lime or calcium carbonate for their improvement. Soils in which the adsorptive capacity is largely saturated with sodium show certain undesirable physical properties.

To epitomize the constitution of the soil in a general formula, we may consider the soil as consisting of more or less decomposed rock and mineral particles of varying sizes associated with a hydrated colloidal complex of clay and organic matter which we conceive as a kind of matrix investing the particles and facilitating their aggregation into compound particles or crumbs. Variation in the terms of this definition accounts for all the variations which we encounter in soil properties. A sandy soil consists mainly of fairly coarse rock or mineral particles with a comparatively small amount of colloidal material investing these particles. A clay consists mainly of finer particles together with correspondingly larger amounts of colloidal material. In a raw subsoil clay, the colloidal complex consists principally of inorganic material, whilst in a surface soil, colloidal organic matter is also present.

There is no essential difference in constitution between soils and such deposits as the London Clay and the Kimmeridge Clay, which, as marine sediments, consist simply of the finer particles and colloidal material of earlier soils. In many of the older Palaeozoic pelitic sediments, along with induration, dehydration of the colloidal material has taken place. Such rocks even on mechanical disintegration do not give plastic clays. It may reasonably be supposed that the colloidal material of any rock which has undergone a considerable degree of heat metamorphism will have suffered dehydration and lost its characteristic properties. For instance, Cambrian slate from North Wales, even when ground to the finest powder, is not plastic and could not be described as a clay. Such rocks, and indeed all rocks made up of silicate minerals, may by secular weathering again produce clay. Mere mechanical comminution cannot produce clay. The small proportions of clay which occur in soils derived from the older Palaeozoic sediments, e.g. in North Wales, may originate both from the hydrolysis of silicate minerals and also from the rehydration of original colloidal material which has lost its colloidal properties through heat metamorphism. Regeneration of colloidal properties by hydration would, of course, be impossible in material from rocks which have undergone intense metamorphism and have become crystalline, as, for example, the crystalline schists of Anglesey. Clay in glacial deposits can only be regarded as originating from pre-glacial, probably Pliocene, weathering. Material brought to a fine state of subdivision by mechanical means

has, of course, when wet the appearance of clay ; but it will be found that it lacks true plasticity and cohesion, and exhibits only in a low degree such colloidal properties as hygroscopicity and adsorption.

The Pedogenic[1] Processes

Soil formation involves a long chain of processes of which the first is the mechanical disintegration of rocks by one or more of the processes well known to geologists. This is closely followed by the addition of organic matter from the residues of the natural vegetation and the appearance of a flora of bacteria, fungi, and other micro-organisms, which can change structural into amorphous or colloidal organic matter or oxidize it completely into carbon dioxide and water.

The chemical weathering of silicates would appear to be a later stage, although the oxidation of ferrous compounds with liberation of iron oxides takes place rapidly along joints and cracks in the earlier stages. The weathering in much of our upland soil in Wales seems to have progressed little beyond this point. The hydrolytic decomposition of silicates, which is the most important chemical decomposition of minerals, is much intensified by the presence in percolating moisture of carbon dioxide. Silicate hydrolysis is thus favoured by the presence of vegetation, which furnishes carbon dioxide, both from the respiration of roots and from the decomposition of plant residues. It is also favoured by high temperatures and is consequently more rapid in tropical than in temperate or cold climates. In desert regions, hydrolysis is impossible owing to lack of moisture, whilst in arctic or alpine regions it is prevented by low temperature. In such regions therefore rock decomposition is predominantly of a mechanical character.

Next in importance as a pedogenic process is the leaching or eluviation of the soil by percolating waters. The amount and nature of this eluviation will depend on the magnitude and distribution of the annual rainfall, on soil and air temperatures, and also on the degree of humidity of the atmosphere. In definitely humid climates, the rainfall exceeds the evaporation and the excess finds its way to the underground water table and to the drainage. In drier climates, where rainfall is exceeded by evaporation, no drainage is furnished and the soil is simply moistened to a certain depth by the rainfall. During intervals of drought the surface of such soils loses water rapidly by evaporation, and there is a capillary rise of water from below until the soil is almost completely dried out. Whilst, in the case of the humid soils there is a constant washing through to the water table and the drainage, in the case of arid soils the moistening and leaching only reaches to a limited depth, below which there is a zone of " dead soil ". Eluviation is both mechanical and chemical. Finer particles are washed down from the surface layers

[1] I am indebted to my friend Dr. Edward Greenly, F.G.S., for this convenient term, which aptly describes the processes of soil formation and metamorphism.

to the underlying layers of subsoil. Mechanical analysis confirms the field observation that subsoils are heavier than soils in texture. An *illuvial* horizon, that is an horizon of accumulation, can be plainly seen in certain soil profiles. All over the south-east of the United States a well-marked horizon of accumulation may be plainly seen in cuttings and other sections. This "pan" represents an accumulation of finer material washed down from the surface layers of the soil.

The mechanical washing of finer particles downwards from the surface horizon is, however, only one aspect of eluviation. Of equal or even greater importance is the downward migration of material in actual or colloidal solution. The nature of this chemical eluviation is closely correlated with the decomposition of the soil moisture. We can broadly distinguish two types of soil moisture, namely, the acid type and the alkaline type. With an alkaline type of soil moisture, the tendency is for the removal of silicic acid in solution, whilst with an acid type of soil moisture, the tendency is for the removal of the oxides of iron and aluminium. The alkali and alkaline earth oxides are leached out from the surface horizons with either type of soil moisture, generally in the form of carbonates or bicarbonates.

The principal pedogenic processes are, then, (1) mechanical disintegration, generally accompanied by a certain amount of oxidation and hydration; (2) addition of the residues of vegetation, which furnish organic matter and render possible the establishment of a micro-flora; (3) silicate hydrolysis, resulting in the liberation of colloidal silicic acid and the oxides of the bases. Of the bases, the sesquioxides form colloidal solutions, which by mutual precipitation with colloidal solutions of silicic acid, form the weathering complex; (4) eluviation, which involves the transport of material from the surface to lower levels both mechanically and in solution.

Classification.

Principles of Classification.

There is probably no natural material for which such a variety of systems of classification have been proposed as for soil. Most of the methods proposed have been of limited application owing to the fact that the experience of workers is generally limited to single soil provinces. Thus the stratigraphical classification of soils which serves for most of Western Europe breaks down where soils in more extreme climates are considered. The same rock may give rise to totally different soils according to the climate and the degree to which the pedogenic processes have proceeded. And so, whilst it may be permissible to speak of Upper Carboniferous or Gault soil over a limited area, such expressions are without meaning when a more universal scale is required. Nor is any securer basis to be found in a petrological classification, since practically identical rocks may give rise to widely different soils under different climatic conditions.

Classification of soils on a purely physical basis is scarcely more

satisfactory from a scientific point of view, since it would involve the grouping together of soils which are otherwise absolutely unrelated. Such a classification is, however, of practical importance, and may be of considerable value in subdividing a more fundamental classification.

The broadest classification of soils is related to the mode of operation of the pedogenic processes and rests ultimately on a climatological basis, since these processes are entirely controlled by climatic factors. The properties of any soil are the resultant of the operation of the processes outlined above. The raw materials differ, but the constant operation of a given set of pedogenic processes tends to produce similar soils from dissimilar materials. It is evidently more logical to classify soils according to the operation of the pedogenic processes which have produced them than according to their raw materials.

The climatological study of soils is based principally on the work of Hilgard in North America, Ramann in Germany, and Dokuchaiev, Sibirtzev, and Glinka in Russia. The climate in any region controls the operation of the principal pedogenic processes, and over any region of approximately the same climate a general similarity of soil type is observed among mature soils, i.e. among soils which have reached a state of pedological equilibrium. Such a similarity may be expected irrespective of the parent rock from which the soils have been derived, and although differences between the parent rocks may persist in the resultant soils, yet these will not obscure a general genetic similarity.

Mature and Immature Soils.

The most comprehensive statement of the principles of the climatic classification of soils is due to K. Glinka. Although many of the details require adjustment, his system forms a useful basis on which, with more abundant and distributed data, a universal system may be built up. Glinka makes a broad preliminary division of soils into *endodynamomorphic* or immature soils and *ektodynamomorphic* or mature soils. In the former group the pedogenic processes have not had full play, and the properties of the soil are largely governed by the character of the parent material and the extent to which organic matter has accumulated in the soil. For such soils a geological or petrological classification may be applicable since the mineral portion of the soil consists mainly of mechanically disintegrated rock which has undergone comparatively little subsequent change, except possibly a certain amount of oxidation and hydration. Endodynamomorphic soils may be expected where time has not sufficed for a mature profile to develop, as, for example, in regions which have been glaciated in relatively recent times or in situations where surface erosion is sufficiently rapid to predominate over eluviation. Much of our soil in Wales is of this character. Even in cultivated areas, the slopes are generally sufficiently steep for the downward removal of material along the surface to keep pace with the weathering of

fresh material. There is thus no opportunity for a mature profile to develop. The soil, as far as the mineral portion is concerned, is simply a geological formation mechanically disintegrated and slightly oxidized. It must be recognized that endodynamomorphic or immature soils form no inconsiderable portion of the earth's surface. In addition to those regions where the strong relief of the surface favours rapid erosion, areas of Quaternary and Recent deposits may be expected to carry immature soils.

Ektodynamomorphic soils are soils in which the pedogenic processes have operated to such a degree as to produce a characteristic succession of soil horizons by which the main types of mature soils may be distinguished from each other. Three main horizons are generally recognized, namely, the A or *eluvial* horizon, the B or *illuvial* horizon, and the C horizon, which consists of the parent material. The A horizon is the stratum from which material has been removed by solution or mechanical transport downwards; the B horizon represents the stratum in which the materials removed from the A horizon accumulate. Both the A and the B horizons may be further subdivided. Thus the top soil, generally distinguished by its darker colour owing to the presence of organic matter, is termed the A_1 horizon, whilst the lower part of the A horizon is termed the A_2 horizon. The C horizon is not necessarily the unaltered geological formation, but may be more or less decomposed mechanically and possibly oxidized. We may regard our endodynamomorphic soils as consisting entirely of the C horizon with the A and B horizons as yet undifferentiated.

Main Climatological Types.

Glinka's main soil types are strictly related to climatic conditions through the extent and nature of the eluviation which has taken place. They are mainly worked out in Russia and Asia, but the considerations are of general application, as will be seen from the ensuing description. It is, of course, necessary to bear in mind that the types in question are all ektodynamomorphic. For the endodynamomorphic soils Glinka's classification seems rather incomplete.

Laterites and Lateritoids.

In the first type of the ektodynamomorphic soils are the laterites of the tropics and the related red and yellow earths of the subtropics. These are described as soils of optimal moistening [1] (Böden optimaler Befeuchtung). The process of lateritization is not completely understood, but it seems probable that it depends on the leaching out by alkaline waters of silicic acid from the weathering complex which results from the hydrolytic decomposition of silicate minerals. The most favourable conditions for this occur in the humid tropics and in extreme cases the residual surface soil consists almost entirely of a mixture of hydrated iron and aluminium oxides.[2] Owing to the high

[1] The writer ventures to suggest the term *euhygric* for this type.
[2] This mixture represents the tropical weathering complex.

temperatures under which they occur, the organic matter will be low in amount in consequence of the rapid bacterial decomposition of plant residues added to the soil. The red and yellow soils of southern Europe represent a less advanced stage of lateritization. Soils of this type are developed originally under forest or scrub vegetation.

Podzols.

Contrasted with the preceding class of soils are the podzols, described as " soils of medium moistening " [1] (Böden mittlerer Befeuchtung). These occur under cold or temperate humid conditions. Like the preceding type, they are developed under forest or scrub, but owing to smaller evaporation the actual soil conditions are moister. This results in poorer aeration and slower decomposition of plant residues added to the soil. The decompositions are of an anaerobic character, and lead to the formation of an acid type of humus. The drainage waters are in consequence acid in their reaction, with the result that instead of silicic acid being removed from the weathering complex in the surface layers, the oxides of iron and aluminium are removed. The surface soil thus becomes impoverished in the sesquioxides and relatively enriched in silicic acid. Podzols are characterized by the development of a bleached horizon immediately below the humous surface layer. Below the bleached layer in typical podzol profiles occurs the illuvial horizon with an accumulation of sesquioxides.[2] As the typical laterites shade off into the lateritoid soils of the subtropics, so in the temperate humid regions incompletely podsolized soils occur, in which, although no well-marked bleached horizon and illuvial horizon are seen, chemical analysis will reveal the downward movement of the sesquioxides and their deposition in an illuvial horizon. Probably mature soils over most of England belong to this type of " podzoloid " soils. It should be remarked that where soils are brought into cultivation a series of changes set in which may completely obliterate the original characteristics of the soil and make it difficult to decide to what class a soil belongs. Most of the soils of Britain are highly artificial, and the general tendency of the pedogenic processes can only be conveniently studied in areas of virgin soil.

Black Earths and their Related Types.

The widely distributed black earths (*tchernosem*) of eastern Europe from an important class in Glinka's classification. They are the " soils of scanty moistening " [3] (Böden mässiger Befeuchtung). Unlike the laterites and the podzols they are soils developed under steppe conditions, that is, under a vegetation of grass, and plants of a similar

[1] Glinka's description may be somewhat misleading, since podzols are generally developed under conditions where soil moisture is excessive during a large part of the year. The writer would suggest the term *dyshygric*.

[2] This illuvial horizon when indurated is frequently known as " iron pan ".

[3] *Oligohygric*.

habit of growth. They are formed under moderately arid conditions, and may be regarded as the most humid of the arid soils. Where they are typically developed, vegetation grows rapidly in the spring and early summer. Summer drought succeeds and the soil conditions are so dry that bacterial decomposition of plant residues is hindered by lack of moisture. There is thus an accumulation of organic matter. Further, owing to the scanty rainfall there is no washing through by drainage and the material brought into solution by water entering the soil from the rainfall is not removed but accumulates in the soil horizons. This leads to one of the characteristic features of arid soils, namely, the development of a calcium carbonate horizon, which approaches the more closely to the surface the drier is the climate. Below this horizon in which the limited circulation of water occurs, is a "dead layer" down to the permanent water table.

The soils of the next class may be considered as differing from the black earths in the more arid conditions under which they occur. They are described as "soils of insufficient moistening" [1] (Böden ungenügender Befeuchtung). Owing to the drier conditions, vegetation is more scanty, and in consequence the soil is poorer in organic matter. This is reflected in the colour of the soil, which is reddish or brown instead of dark brown or black, as in the case of the soils of the preceding class. These soils are, in fact, called the "chestnut-coloured earths" (kastanienfarbige Böden). They form a belt on the desert side of the black earths. Both black earths and chestnut earths may be seen in the United States under climatic conditions similar to those of Russia. The calcium carbonate horizon is nearer to the surface in the case of the chestnut earths than in the case of the black earths. The writer had recently some opportunities of examining soils of this type in the western United States, and they agree remarkably well with Glinka's descriptions of the corresponding European soils. With the chestnut earths may be grouped soils formed under still more arid conditions, and in which the reddish-brown colour due to the presence of small amounts of organic matter gradually fades into the grey colour of the desert soils.

Peats and their Related Types.

The remaining classes in Glinka's scheme fall somewhat outside the scope of the principles used in arriving at the types mentioned above. "Soils of excessive moistening" [2] (Böden übermässiger Befeuchtung) include peat and marsh soils with their related species. In the peat soils, of which there are a large number of sub-classes, excess of moisture results in deficient aeration and an anaerobic type of microbiological decomposition of plant residues. This type of decomposition is characterized by the accumulation of humified organic matter, and the formation of what is commonly known as peat. Glinka groups with these soils, but under a separate

[1] *Hypohygric.* [2] *Hyperhygric.*

heading, the marsh soils. It would seem, however, that such soils might be more appropriately grouped with the endodynamomorphic or immature soils.

Saline and Alkaline Soils.

The remaining class in Glinka's scheme is only of limited interest for western European pedologists. It includes the saline and alkali soils. By saline soils are understood soils in which there is an accumulation of salts, generally sodium sulphate or chloride, at or near the surface. Related to them are the "alkali" soils in which sodium sulphate or chloride are replaced by sodium carbonate. Alkali soils are closely related to saline soils, and are probably derived from them by leaching out of excess of the chlorides and sulphates and decomposition of the complex sodium silicate adsorption compounds formed by the reaction of the neutral salts with the weathering complex. The exact conditions of origin of the saline and alkali soils are not perfectly understood. Whilst in some cases they may originate by the accumulation under arid conditions of sodium salts formed from the products of silicate hydrolysis, in other cases, as, for example, near the Caspian Sea, and in the Great Basin of North America, these salts may owe their origin to former inland seas.

Soil Surveys.

Considerable attention has been given in the foregoing remarks to the climatological classification of Glinka. This does not imply that there is finality in such a classification: it is used rather to illustrate the considerations which may be helpful in arriving at a universal classification. Before such a classification can be obtained a much more extended study of soils from the purely scientific point of view is necessary. With the pressure of applied research on workers in agricultural institutions, it is scarcely to be expected that they can be responsible for such a task, unless, as in the United States, some such organization as the Soil Survey is set up. It may therefore be urged that the study of soils should receive more attention from geologists. One of the most obvious directions in which this could be secured would be the inclusion of a more detailed consideration of the soil among the duties of workers in geological surveys in all parts of the world. Ability to recognize the principal soil horizons would, of course, be necessary. In addition, the collection of typical profile samples would be necessary and would naturally entail provision for chemical and physical examination of samples thus collected.

Soil survey work has been in progress in this country for a number of years. Up to the present no very clear idea has prevailed as to the aims and objects of this branch of research. Whilst in some cases it has been possible to point to successes on the practical side, it must be confessed that, on the whole, the results have not been encouraging, for the reason that soil characters form only one group and in some cases a comparatively minor group, among the factors

which influence plant growth. The writer ventures to submit that the time has come for a broader view to be taken of soil survey work and for the field study of soils to be carried out on similar lines to those of the Geological Survey. Whilst this may seem rather a hazardous suggestion for an agricultural chemist to advance, it may be noted that the Geological Survey is not required to show an immediate practical application for its work. Ultimately the shortest route to the utilization of scientific work is that of pure research for its own sake. It is not an unreasonable contention that the study of soils from the purely scientific standpoint will in the long run bring its own application to their cultivation and improvement.

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Fossil Arthropods from the Tyne Coalfield.

By E. Leonard Gill.

Introductory.

REMAINS of arthropods are among the rarest of fossils in the Coal Measures. Rare as they are, however, they have been recorded in some numbers from nearly all the principal coalfields, including those of the British Isles, the Continent of Europe, and North America. But of the larger British coalfields, that of Northumberland and Durham appeared till recently to be conspicuously poor in fossil arthropods. It has been reserved for Mr. William Eltringham, of West Ryton, near Newcastle-on-Tyne, to demonstrate by careful

and intelligent collecting that this coalfield does yield a variety of interesting arthropod fossils. His success, in fact, makes it practically certain that if other localities and horizons were worked in the same careful and persistent way, the Coal Measures of Northumberland and Durham would furnish as much information on the arthropod fauna of the coal period as has been gained, for instance, from those of Staffordshire and Lancashire.

Mr. Eltringham's collection has been made in a single quarry, that of the Phoenix Brickworks at Crawcrook, on the Durham side of the Tyne valley, 7 miles west of Newcastle. In the shale that is here worked for brick-making there occur bands of ironstone, chiefly in the form of layers of clay-ironstone nodules. It is a well-known though still unexplained fact, that clay-ironstone nodules in the Coal Measures commonly contain the remains of a fauna that is almost or quite unrepresented in the associated beds. In particular it is from clay-ironstone nodules that nearly all the terrestrial Coal Measure arthropods have been obtained—at any rate, so far as Britain is concerned—and Mr. Eltringham's experience bears out that of other collectors. He is the first who has systematically worked a clay-ironstone deposit in this coalfield, and he has been rewarded by finding practically all the fossil arthropods known from the coalfield up to the present time.[1]

The beds worked at Crawcrook are in the Middle Coal Measures and are associated with a thin coal seam known locally as the Crow Coal. The horizon is near that of the well-known Low Main seam. The bulk of the collection made by Mr. Eltringham consists of fossil plants. These were worked out by the late Dr. R. Kidston (1922) and added largely to what was known of the flora of the coalfield. The animal remains have been shown to me from time to time ; the insects, represented only by two detached wings, have been submitted to Mr. Herbert Bolton, and of the rest all that seemed to be of any importance have now very kindly been lent to me by Mr. Eltringham. In this paper I figure, with such explanatory notes as appear to be necessary, some specially interesting specimens from among the arthropods.

Associated Fauna.

By far the majority of the nodules, when they contain anything at all, are formed round the remains of plants, *Neuropteris* fronds occurring perhaps more commonly than anything else. Animal remains are rare in comparison. Fish scales, those of *Strepsodus* in particular, are among the least rare of them. The following list, which includes all the animal remains that I remember to have seen in Mr. Eltringham's collection, will show the sort of fauna that is

[1] There are only two previous records of terrestrial arthropods : the wing of an insect, *Phylomylacris mantidioides* (Goldenberg), from a much higher horizon (see Bolton, 1922, p. 125, pl. ix, fig. 1), and a specimen of the arachnid *Anthracosiro woodwardi* Pocock, from Crawcrook, referred to later, p. 462.

represented in the nodules. An asterisk indicates that a specimen is figured in the present paper.

Fish remains :

Strepsodus scales and shoulder girdle.
Ctenodus scales and tooth.
Hybodont shark's teeth, one small group.
Gyracanthus spine.
Coprolite with scales and bones of Palaeoniscids, *Sagenodus*, etc.
Palaeoxyris (fish's egg capsule ?), several good specimens (and one ? *Vetacapsula*).

Insect remains :

Wing, type of *Hypermegethes northumbriae* Bolton (see Bolton, 1921, p. 32, pl. i, fig. 4).
Another large wing, undetermined.

Myriopods :

**Euphoberia ferox* (Salter), one.
Euphoberia sp. cf. *E. browni* Woodward, one.

Arachnids :

**Eophrynus pococki* sp. nov., one.
**Anthracosiro woodwardi* Pocock, several.
Carapace of scorpion (*Cyclophthalmus* ?).

Merostomata :

Prestwichia, comparatively frequent in one patch.
Belinurus, only one or two.
A possible Eurypterid abdomen and tail.

? Merostomata :

**Cyclus* sp. cf. *C. johnsoni* Woodward, one.

Crustacea :

Arthropleura armata Jordan, a number of detached plates.

Incertae sedis :

**Camptophyllia eltringhami* gen. et sp. nov., one.
**Camptophyllia fallax* gen. et sp. nov., one.

The intermingling of terrestrial and aquatic forms of life is noteworthy. Even such a presumably pelagic creature as a hybodont shark is represented in near association with insects, millipedes, and arachnids.

Descriptions of Figured Examples.

Myriopoda (*Diplopoda*).

Genus Euphoberia Meek and Worthen.

Euphoberia ferox (Salter). (Fig. 1.)

The specimen represented in Fig. 1 would come under this species as interpreted by the late Dr. Henry Woodward (1887, pp. 6–10, Pl. I). The genus *Euphoberia*, as it was left by Scudder and Woodward, appears a rather mixed assemblage, but any re-examination of it must be undertaken by some one with a good

knowledge of the Myriopoda in general.[1] Similarly I refrain from discussing whether the specimen is really of the same species as Salter's *Euphoberia* (" *Eurypterus* ") *ferox*. It is at any rate closely related to it. It shows twenty-five segments more or less completely from the dorsal aspect. Measured round the curve the specimen as preserved is 150 mm. long. In the figure I have drawn the segments as though they were all lying in the same plane ; in the nodule itself they are tilted down towards the margin all round, and in a general view are seen somewhat edgeways. Neither head nor tail is in view. Towards the head end (the lower end in the figure) each segment is

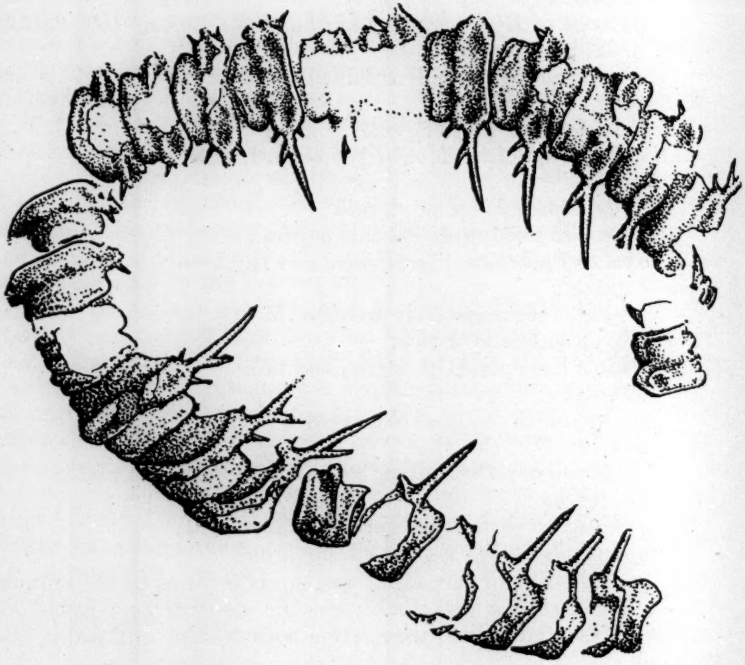

FIG. 1.—*Euphoberia ferox* (Salter). Coal Measures, Crawcrook. About one-and-a-half times natural size.

tipped forward into the matrix. Further back the segments are more nearly in their natural position, though they are probably much more widely spaced longitudinally than they were in the living animal.

Comparison with Dr. Woodward's figures (GEOL. MAG., 1887, Pl. I) brings out a few points of interest. His fig. 4 presumably shows

[1] The Rev. Dr. S. Graham Brade-Birks is bringing his knowledge of existing myriopods to bear on the fossil forms, and it is to be hoped he will before long be in a position to deal comprehensively with those found in the Palaeozoic rocks.

the segments in natural relationship, with the anterior half (prozonite) of each overlain by the posterior half (metazonite) of the one in front. The bifid lateral spines in the present example differ from most of those figured by Dr. Woodward in being forked nearer the base and in having the posterior branch much longer than the anterior. The small and simple lateral spines also, one in front of the base of each bifid spine and one behind, seem to be more nearly equal in size. Some of the hinder segments, owing to the stretched condition in which the animal was fossilized, show the complete form of the tergites unusually well. The hind margin is slightly concave, but nearly straight; the front margin is carried out to a very blunt point in the median line, and there is a marked constriction in front of the spine-bearing lateral expansion. One segment, the sixth counting backwards from the anterior end, is seen in partial side view and compares well with those shown from the same aspect in fig. 13 of Dr. Woodward's plate. So far at least as this specimen is concerned, we seem to be dealing with a flat-backed millipede. It is difficult to believe that its tergites can have been so strongly arched as in Dr. Woodward's restoration (fig. 11 of the same plate), with the branched spines springing at right angles from their lateral surface. Some of the fossil millipedes at present known as species of *Euphoberia* do appear to have been more or less cylindrical, but it may be suggested that that is a reason for separating them generically from *ferox* rather than for assuming that *ferox* also was cylindrical.

There is another millipede[1] in Mr. Eltringham's collection, but it is not well enough preserved for figuring and discussion. It is much smaller in diameter than *Euphoberia ferox*. A considerable length of it is seen in the form of a rough cast, with traces of limbs. So far as it can be made out at all it bears a general resemblance to *Euphoberia browni*, Woodward.

Arachnida (*Anthracomarti*).

Genus Eophrynus H. Woodward.

Only one species of this genus, *Eophrynus prestvici* (Buckland), is satisfactorily known. It has been studied in great detail from a nearly perfect specimen by Mr. R. I. Pocock (1902, fig. on p. 490), and in view of his great services in extending and systematizing our knowledge of the Carboniferous Arachnida, I venture to associate Mr. Pocock's name with the new species here figured and described.

Eophrynus pococki sp. nov. (Fig. 2.)

Resembling *E. prestvici* in general form and size, but apparently somewhat broader and presenting the following structural differences.

[1] Since the above was written Mr. Eltringham has discovered several more fossil millipedes at Crawcrook, including an example of *Euphoberia ferox*, which shows a cross-section of the body and legs. These specimens I have submitted to the Rev. Dr. Brade-Birks.

Carapace with four lateral areas instead of three. Opisthosoma with two longitudinal furrows on either side of the mid-dorsal line instead of only one. One anterior tergite, presumably the second, greatly enlarged.—Type and only known specimen in a clay-ironstone nodule from the Middle Coal Measures (Crow Coal) of Crawcrook, near Ryton-on-Tyne, in the collection of Mr. William Eltringham.

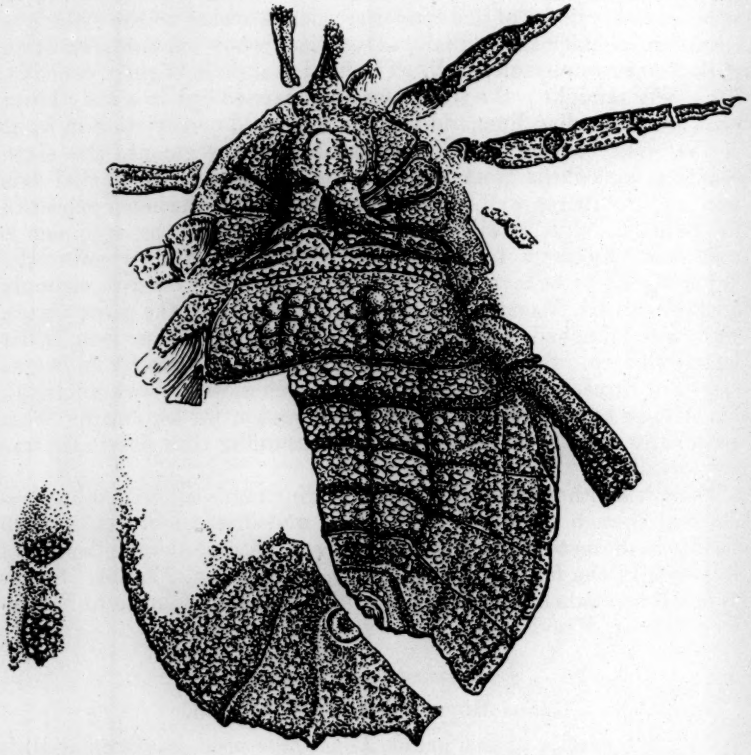

FIG. 2.—*Eophrynus pococki* sp. nov. Coal Measures, Crawcrook. Three times natural size. (The femora of the two first walking legs on the right are greatly foreshortened.)

The specimen is in several fragments, but it is possible to place them all in their correct relative positions as has been done in Fig. 2. The length (carapace and opisthosoma) is 29 mm. For the most part it is the dorsal surface that is shown, but the left posterior part of the opisthosoma is represented by a fragment of the ventral surface, shown in the figure as an impression. Both surfaces are closely tuberculated, but the tubercles on the pleural laminae and on the underside are less sharply cut than those on the more central parts of the tergites. As in *E. prestvici*, there are larger tubercles

bordering the longitudinal grooves of the tergites ; they are particularly prominent on the enlarged anterior tergite.

The carapace, though broader, has the same general form and structure as in *E. prestvici*. It shows the same median prominence with a deep median groove posteriorly, and the same lateral areas corresponding with the underlying coxae of the walking legs. But there is an additional (fourth) area, wanting in *E. prestvici*, much narrower than those in front of it and apparently overlying the anterior border of the last coxa. Outside these areas the carapace is bordered by a smoother flange with a slightly notched outline, drawn out postero-laterally to a triangular point. The anterior half of the median prominence seems to differ in detailed structure from the same region in *E. prestvici*, but it is not well enough preserved to justify a definite statement. The lateral areas are continued up the sides of the median prominence, but here they are smooth, not tuberculated. The hinder border of the carapace is not distinctly recognizable in this specimen ; the region is crossed by several transverse grooves (some of them probably caused by genital plates or other structures of the underside), but one which continues the line of the right postero-lateral angle and passes immediately behind the fourth (narrow) lateral area almost certainly marks the actual boundary.

The distinguishing characters of the opisthosoma as compared with that of *E. prestvici* have been stated above in the specific diagnosis. What appears to be the first tergite is very narrow (i.e. short from front to back). The great extension of the next tergite, here regarded as the second, forms the most striking point of difference from *E. prestvici*. On this tergite also the longitudinal furrows of the admedian pair take their rise, bordered by very large tubercles. The more laterally placed furrows, one on each side, seem to begin on the next (third ?) tergite. All the furrows are bordered throughout by more or less enlarged tubercles. In spite of the presence of two pairs of furrows, however, the lateral ones are further from the margin than are those of the single pair in *E. prestvici*, and the pleural laminae are consequently wider in the present species. In *E. prestvici*, furthermore, the laminae bear a single large tubercle each, and of this there is no trace in this specimen. The laminae of the right side, where alone they are seen, are crossed by several irregular folds, but these are plainly accidental and are probably due to underlying structures. As in *E. prestvici*, there are two spines on the hinder margin at each side at the junction of the posterior segments, but they are less pronounced than in the other species.

Portions of most of the appendages are seen, but only one, the second walking leg on the right, is at all nearly complete. That leg and the one in front of it are seen as impressions of the underside ; their femora are embedded in a rising wall of the matrix, and as the little that is seen of them is strongly foreshortened from above, they hardly appear in the figure. The femur is really the longest

joint of the limb, and this should be allowed for in looking at the figure. So far as comparison is possible, it would appear that the appendages in the two species are much alike, though the single tarsus shown here seems to differ from one figured by Mr. Pocock in that it is two-jointed and ends in a well-marked claw.

Genus ANTHRACOSIRO Pocock.

Anthracosiro woodwardi Pocock. (Fig. 3.)

At Crawcrook, as elsewhere in the English Coal Measures, this appears to be the commonest terrestrial arachnid. It was the only one known from the Tyne coalfield before Mr. Eltringham formed

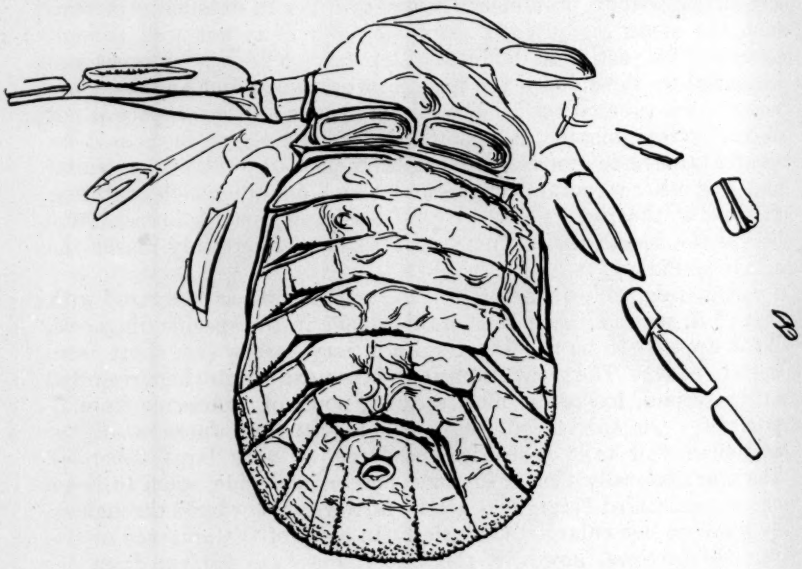

FIG. 3.—*Anthracosiro woodwardi* Pocock. Coal Measures, Crawcrook. Showing partially separated tergal plates. Four times natural size.

his collection: a single specimen was obtained by me in 1909 from the same quarry at Crawcrook, and is now in the Hancock Museum at Newcastle. (I described it as a new species, *A. latipes*, but Dr. Bather subsequently showed, by removing some of the matrix from the type specimen of *A. woodwardi*, that the expanded limb-joints were a character of that species also.—See Pocock, 1911, pp. 71, 72.)

Mr. Eltringham's collection contains three specimens of *A. woodwardi*. Of one of them I give an outline figure (Fig. 3), because, though the carapace is badly preserved, the abdomen (opisthosoma) is crushed in such a way as to show the true shape of the individual tergal plates, and this is not seen in any specimen

yet figured. At the point on each tergal plate where in a well-preserved example it is bent upwards and backwards to form a pleural lamina there is seen in this specimen a distinct constriction. The partial separation of the plates further suggests that in this form, at least, the opisthosoma was less rigidly welded together than has generally been held to be the case in the Anthracomarti.

At the hinder end some details of the sternites, and, as usual, the anal operculum, are printed through from the ventral surface. One further point may be mentioned. In Mr. Pocock's restoration of *A. woodwardi* (1911, p. 71, fig. 35) the legs are all represented as turning forward from the femora, as in a scorpion. Mr. Pocock must certainly have had evidence to go upon in so figuring them, but in this and the other specimens that I have seen the evidence, so far as it goes, would suggest that, as apparently in other Anthracomarti, the legs were carried in the way normal to actively running arachnids.

Merostomata ?

Genus Cyclus de Koninck.

Cyclus sp. cf. *johnsoni* Woodward. (Figs. 4 and 5.)

Mr. Eltringham's collection contains up to the present only a single example of this much-debated genus, but it is probably the most important, as it appears to be also the largest, example yet discovered. Its special importance lies in the fact that it is the first known *Cyclus* showing distinctly preserved limbs. The affinities of *Cyclus* have long been under discussion, and decisive evidence as to the nature of the appendages was the chief thing needed to throw light on the problem. Dr. B. N. Peach (1882, p. 526) found traces of appendages in some small specimens from the Lower Carboniferous (Calciferous Sandstone shales) of Langholm, Dumfriesshire, but they were much too obscure to be of service. Twelve years later Dr. Henry Woodward (1894) described and figured antenna-like appendages in *Cyclus johnsoni*. In the same paper (text-fig. 2, p. 534) he also figured " biramous swimming appendages ", but though I have not seen the specimen I find it hard to believe that these were parts of the animal. They might possibly be fragments of vegetation such as are commonly found scattered over the fractured face of the nodules.

A comprehensive study of the structure and relationships of *Cyclus* is, I understand, being undertaken by Mr. Arthur T. Hopwood, of Manchester University, and I hope that Mr. Eltringham's specimen will be submitted to him. In the meantime I will indicate some of its more interesting features. Fig. 4 shows the general appearance of the specimen. Except in size—the carapace is about 18 mm. long—it closely resembles Dr. Woodward's species *C. johnsoni*. Much of the original dorsal surface is preserved round the margins (Fig. 5*a*), but it is missing over the greater part of the fossil, and the usual details of a wedge-shaped central area and radiating (coxal ?) impressions are shown

through the ventral integument. The striking feature of the specimen is constituted by the limbs which are seen projecting beyond the carapace. They are of so much interest that I have figured them separately on a larger scale (Figs. 5*b*, *c*, *d*), showing their appearance on each half of the nodule. Their bases are surrounded by indefinite material which very probably indicates that they have slipped outwards from below the carapace and are not in their natural position. Three of them are well preserved, and

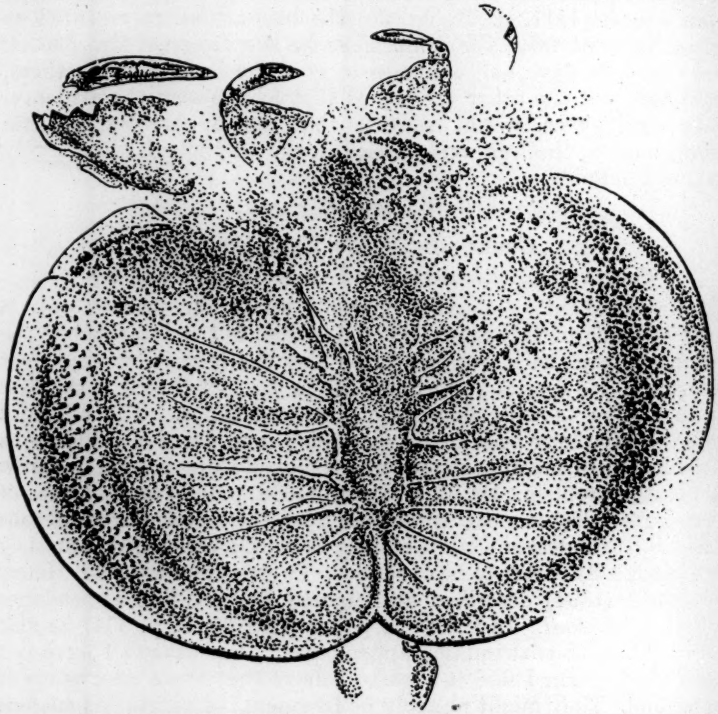

FIG. 4.—*Cyclus* cf. *johnsoni* Woodward. Coal Measures, Crawcrook. Showing some of the limbs. Three times natural size.

in each of these the terminal joint is pointed and is much more strongly calcified or chitinized than the rest. None of the terminal joints appears to be chelate. Each of them is attached to a proximal joint of expanded and roughly triangular shape. From their rather ill-defined form it may be inferred that these proximal segments of the limbs were comparatively soft and were probably shielded by the carapace. The details of their structure are by no means clear, but they show traces (especially marked in the large outer limb) of serrations towards their distal ends.

It is perhaps doubtful whether these appendages will prove quite

decisive as to the crustacean or arachnid affinities of *Cyclus*. It is undeniable, however, that they bear a remarkably close resemblance to the appendages of many parasitic copepods. The pointed, non-chelate and strongly-chitinized terminal joints, mounted on more

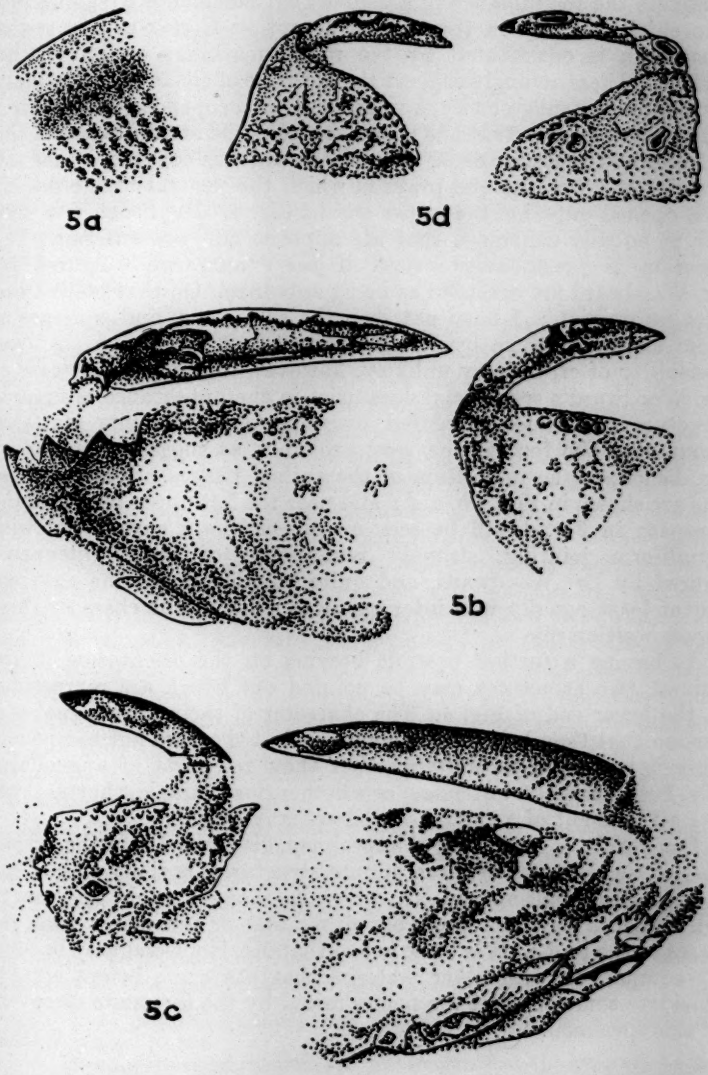

FIG. 5.—*Cyclus* cf. *johnsoni* Woodward. Enlarged figures of parts of the specimen shown in Fig. 4. *a*, margin of carapace; *b*, limbs shown on left in Fig. 4; *c*, counterpart of same limbs; *d*, limb shown on right in Fig. 4, with its counterpart. (*a* six times, *b*, *c*, *d* eight times natural size.)

proximal joints which are swollen and have an almost membranous integument, can be nearly perfectly matched, for example, in the "second antennae" and maxillipeds of *Cecrops* and other Caligulidae; and the other antennae figured by Dr. Woodward would complete the resemblance in a degree that seems highly significant. The chief difficulty in the way of accepting *Cyclus* as a copepod crustacean is constituted by the radial markings on its ventral surface. These strongly suggest the imprints of coxae; and radially disposed coxae suggest a xyphosuran and not a copepod relationship.

Another question that has been debated is the identification of the anterior and posterior ends. Dr. Woodward was convinced that the anterior end was the one towards which the ventral wedge-shaped area opened out—i.e. the upper end in Fig. 4. Dr. Peach was, and still is, equally convinced that the opposite end was anterior. The question is presumably settled if the "antennae" figured by Dr. Woodward are accepted as being antennae. On that point I can offer no opinion; I have not seen the specimens, and squeezes of them kindly sent me by Dr. Bather are not conclusive. A bare possibility of error (very unlikely, however, to apply in the case of Dr. Woodward's specimens) does exist in the appearance of organic structure sometimes presented by numerous little pits scattered about over the fossils, due very probably, as suggested to me by Dr. Peach, to decomposition of the animal tissues. Some of these pits are shown in Figs. 5*b*, *c*, *d*; and near the left upper border of the carapace in Fig. 4 will be seen an object like a curved rod with moniliform jointing, strongly reminiscent of the "antennae" figured by Dr. Woodward, and quite possibly a genuine antenna, but at least equally well interpreted as a fortuitous chain of these decomposition pits.

As having a further possible bearing on the orientation of the animal, two structures may be pointed out which are represented at the lower end of Fig. 4. The character of their surface makes it certain that they belong to the animal, but they are not completely enough preserved to show whether they are parts of appendages (Dr. Peach suggests antennae) or whether, for example, they indicate the attachment of a caudal or abdominal segment.

Dr. Peach, in examining the specimen, discovered near the middle line of the disc two or three minute structures, radially ribbed and shaped like a half-opened fan, which he thought might be parts of gill books. They are probably either that or jaw-plates from the bases of the limbs. It is to be hoped that Mr. Hopwood may be able, by comparison with other material that has come before him, to elucidate some or all of the points raised by the fortunate discovery of this specimen.

Incertae sedis.

Genus CAMPTOPHYLLIA nov.

Head unknown. Body made up of at least eight similar segments, followed by a modified tail segment. Each body-segment apparently

covered dorsally by a wide median tergite, which is flanked on either side by a narrower plate; the segment completed on each side by a leaf-like pleural expansion with a rounded anterior border and a postero-external angle drawn out to a backwardly directed point. Segments decreasing regularly in length from before backwards. Type species *Camptophyllia eltringhami* nov.

Camptophyllia eltringhami gen. et sp. nov. (Fig. 6.)

Body-segments as described above for the genus. Tail segment apparently flanked by pleural expansions of the same form as those of the body-segments,[1] and completed posteriorly by a corresponding expansion which bears a median dorsal keel continued backwards into a median spine.—Type and only known specimen in a clay-ironstone nodule from the Middle Coal Measures (Crow Coal) of Crawcrook, near Ryton-on-Tyne, in the collection of Mr. William Eltringham.

Up to the present I have been unable to discover to what arthropod class this remarkable fossil should be referred. In the nodule as it was split in the first instance only one side of a few of the anterior segments was exposed, and at an early stage of the removal of the obscuring matrix these few segments bore every appearance of belonging to the abdomen of some such schizopod (? decapod) crustacean as *Perimecturus*. But as more of them were uncovered it became clear that they were too numerous for that interpretation, and the final clearing of the tail segment, proving the absence of any swimming fan, showed that the fossil was not even a portion of some crustacean of the stomatopod pattern. Its general appearance is undoubtedly that of an isopod, and I am inclined to consider it as such provisionally. Several Carboniferous fossils have already been described as isopods, and in spite of the doubts attaching to them,[2] it would seem probable on general grounds that crustaceans of such comparatively simple type as the isopods should be in existence at least as early as the decapods; and of "schizopods", if not of true decapods, there are abundant remains even in some of the lowest Carboniferous beds.

But there are considerable difficulties even in regarding the animal as an isopod. One is the presence of subsidiary lateral plates flanking the main dorsal plate in each segment; but it is just possible that the apparent lines of division are in reality of the nature of surface ornament. Another difficulty is the regular gradation in size of the segments. It seems probable, in fact, that if *Camptophyllia* was an isopod at all it was an extremely primitive one.

[1] But these pleural expansions may belong to a last body-segment. See under *C. fallax*, p. 471.

[2] Dr. Peach gives it emphatically as his opinion that the Isopoda did not arise till later than the Carboniferous period. But it is frequently noticeable that as more facts and specimens accumulate bearing on the palaeontology of a group of animals the effect is to throw back its probable origin to a more remote geological past.

The specimen as preserved is 39 mm. long. The true dorsal surface is apparently only preserved on the pleural expansions and on a few

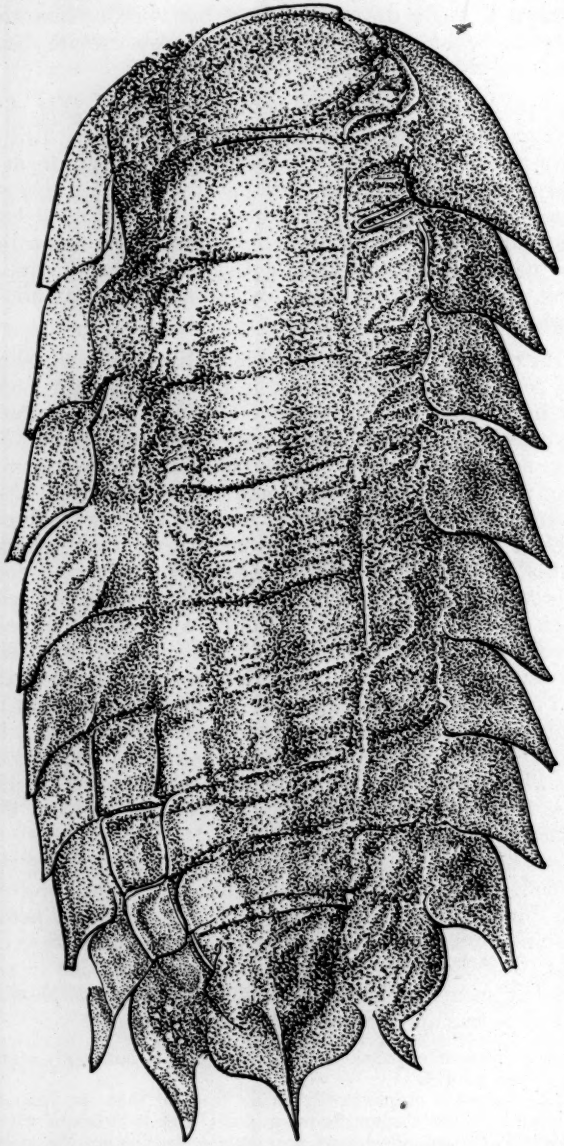

FIG. 6.—*Camptophyllia eltringhami* gen. et sp. nov. Coal Measures, Crawcrook. Four times natural size.

of the left-posterior tergal plates. The lines and markings over the rest of the fossil are probably a mixture of those of the dorsal and ventral integuments. Some of the anterior segments show, just inside the right pleural expansions, a series of transverse ventral pits. These might be the bases of limbs, but there are two of them to each segment (a fact which led Dr. Peach, who has examined the fossil, to suggest that it may be an aberrant millipede). The anterior end of the specimen is somewhat puzzling. In advance of the foremost segment and embraced laterally by a forward extension of its pleura is an oval space, obviously belonging chiefly to the ventral surface. This looks like the area of attachment of the head. It is perhaps as likely, however, that it is no more than a ventral forward extension of the segment such as would be disclosed as part of any of the other segments if the one in front had been completely removed. The leaf-like pleural expansions seem to overlap each other considerably. It is easy to imagine, for example, those of the second segment as being carried forward in a curve that would underlie most of the area covered by the dorsal plate of the first.

Camptophyllia fallax sp. nov. (Fig. 7.)

Body-segments as described for the genus. Tail-segment without pleural expansions and with its posterior expansion continued backwards as a broad flange, which is as long as the median keel, so that the latter does not project beyond it as a spine.—Type and only known specimen in a clay-ironstone nodule from the Middle Coal Measures (Crow Coal) of Crawcrook, near Ryton-on-Tyne, in the collection of Mr. William Eltringham.

Another remarkable fossil collected at Crawcrook by Mr. Eltringham is the specimen represented in Fig. 7. At first sight it has little apparent connexion with the *Camptophyllia* shown in the preceding figure. Its general aspect, indeed, is so much that of the opisthosoma of one of the Anthracomarti that a very good palaeontologist, to whom Mr. Eltringham showed it, had no hesitation in identifying it as an arachnid of that order, probably related to *Kreischeria*. But apart from its size, a closer examination, particularly of the hinder segments, would have revealed great difficulties in the way of such an interpretation ; and the preparation and study of the specimen described above as *Camptophyllia eltringhami* brought out so many details of structure common to the two forms that I can hardly doubt their close relationship.

The specimen is 28 mm. in length. It exists as a hollow impression in one half of a nodule ; the other half, which would bear the actual fossil in relief, has been lost. The drawing (Fig. 7) was made from a plasticine squeeze. It will be seen that, as in *Camptophyllia eltringhami*, the body-segments are covered dorsally by median plates, flanked on each side first by smaller plates and outside these by pleural expansions. Most of these pleural pieces are crumpled or otherwise distorted, but the best preserved of them show a form

much like that of the corresponding parts of *C. eltringhami*. Lying against the fore-part of the specimen on the right is the inverted lateral half of a segment, seen from the ventral surface. It shows the shape of the undistorted pleural expansion, and is further instructive as suggesting that on the underside there was a pair of plates corresponding to the single median dorsal plate ; and if the detached half-segment be imagined as turned over and placed in its proper position, it will be seen that the outline of the admedian plate explains the markings which are more or less clearly printed through from below near the hinder border of each of the median dorsal plates.

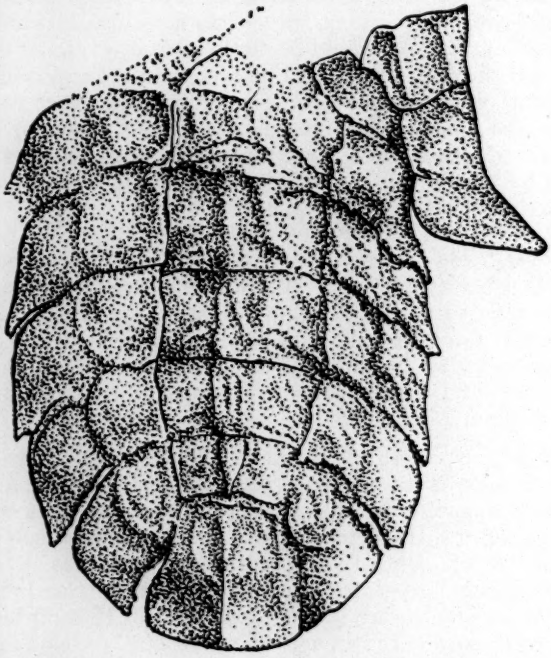

FIG. 7.—*Camptophyllia fallax* sp. nov. Coal Measures, Crawcrook. Three times natural size.

The dorsal surface in general is rather better preserved than in the specimen of *C. eltringhami*. An irregular ridge down the centre of it may belong to it or may just possibly be the imprint from below of a line of median ventral plates. On the last body-segment this ridge ends in a sharply defined lanceolate point.

The tail-segment, it must be confessed, is difficult to bring into any relationship with that of *C. eltringhami*. The median keel is a common feature, but there the resemblance seems practically to end. The segment may quite possibly be incomplete. After chipping out the other specimen I rather expected to find that the removal of

a little matrix on this one would reveal a tail spine and perhaps some trace of pleural plates. But tentative chippings seem to show that the first splitting of the nodule had already exposed the true boundaries of the specimen, whether complete at the hinder end or not. Perhaps the likeliest explanation of the apparent discrepancy in structural plan of the tail end in the two specimens is this: that what looks like the tail-segment in the example of *C. eltringhami* is, in reality, the last body-segment *plus* the tail-segment. The mid-dorsal surface in this part is especially poorly preserved, and a suture (possibly also a lanceolate point) may be altogether obliterated. This would leave as the only essential difference the fact that whereas in *C. eltringhami* the median keel projects beyond the flange, in *C. fallax* the flange is longer and embraces the whole length of the keel.

The further elucidation of these two interesting fossils must be left to specialists or to the fresh light that may be gained from the discovery of additional specimens.[1]

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Note on the Nature and Age of Scottish Rocks bearing Xenocrysts of Anorthoclase or Soda-microcline.

By V. A. EYLES, B.Sc.

IN a recent paper on the age of the East Fife volcanoes, Mr. Balsillie has laid stress on the occurrence of xenocrysts of soda-microcline in various ashes and agglomerates in East Fife.[2] These Fifeshire occurrences are well known, but it may be of interest to draw attention to the fact that xenocrysts of similar composition have been encountered in at least two other Scottish localities. Dr. Flett[3]

[1] Mr. Eltringham has since discovered a further specimen of *Camptophyllia eltringhami* which, if it can be satisfa torily developed (it is in an exceedingly refractory nodula), promises to reveal much of the structure that is wanting in the example here figured.

[2] D. Balsillie, "Further Observations on the Volcanic Geology of East Fife": GEOL. MAG., Vol. LX, 1923, p. 540.

[3] J. S. Flett, "The Geology of the Country near Oban and Dalmally" Explanation of Sheet 45): *Mem. Geol. Surv. Scotland,* 1908, p. 127.

describes a monchiquite dyke from Camas an Fhais, Ardmucknish, Argyll, which contains large rounded xenocrysts of anorthoclase. These, he states, have the same optical properties as the xenocrystic felspars occurring in monchiquite dykes near Elie, Fife. He goes on to say, referring to the monchiquite and other dykes of Ardmucknish, "There can be little doubt that these rocks are of Tertiary age." I believe, however, this last supposition is incapable of definite proof, for instance, the dyke carrying the anorthoclase is not seen in contact with any rock of later date than Highland Schists.

Another occurrence, hitherto unrecorded, was noted by myself during the course of the resurvey of Ayrshire by the Geological Survey. In this case, the xenocrysts occurred in a block of rock which may be styled an augite-monchiquite, and which was found in the agglomerate of Heughmill volcanic neck, 2½ miles N.W. of Tarbolton. This vent pierces nearly the whole of the Barren Red Coal Measures. It is undoubtedly of post-Carboniferous age, and probably of the same date as the Permian or New Red lavas which outcrop about 100 yards to the south. The felspar constituting the xenocrysts presented rounded and embayed outlines, and in its optical properties appears to correspond very closely with those occurring in Fife. Its refractive index was taken in oil and gave $\mu = 1{\cdot}528$, the same exactly as that of the felspars examined by Mr. Balsillie.

It may be added that Dr. G. W. Tyrrell records detached crystals of alkali-felspar from the ashes of vents of supposed Permian age at Patna Hill, Carskeoch, and Keirs Hill in South Ayrshire, and similar crystals enclosed in monchiquite intrusions penetrating the two latter necks.[1]

The rocks enclosing these alkali felspars (soda-microline or anorthoclase where determined from Fife, Ardmucknish and Heughmill) are in all cases of monchiquite type. It would appear, therefore, that such felspar xenocrysts are characteristic of a particular type or modification of basic magma, namely that resulting in monchiquitic rocks. It seems dangerous to lay too much stress on their occurrence as an index of geological age. Mr. Balsillie has used the felspar xenocrysts of East Fife as an argument against a post-Carboniferous date for the ashes and intrusions which enclose them. It is at least certain that his conclusions will not bear extension into Ayrshire.

[1] G. W. Tyrrell, "The Igneous Geology of the Ayrshire Coast from Doonfoot to the Heads of Ayr": *Trans. Geol. Soc. Glasgow*, vol. xvi, pt. iii, 1917–18, p. 359.

REVIEWS.

THE EVOLUTION OF MAN: ESSAYS. By G. ELLIOT SMITH, F.R.S. pp. 159. Oxford University Press, 1924.

IN this small volume Professor Elliot Smith has reprinted his presidential address to the Anthropological Section of the British Association in 1912, an address to the British Academy in 1916, and a lecture to the Royal Institution in 1924. He has also added a foreword, with general observations on the evolution of the Primates and the human family, two diagrammatic genealogical trees, and a map showing the supposed wanderings of the Primates during the Tertiary period. The essential theme of the book is the importance of the cultivation of vision in the evolution of man's intellect; but it ranges over the whole subject, and makes many references to the fossil remains of man and the Primates most nearly related to him. We commend it to all who are interested in the pedigree of man as interpreted by one of the foremost students of the various problems connected with it.

The known fossil remains of the Primates are too scanty to admit of many conclusions being drawn from them, but Professor Elliot Smith boldly concludes that the order originated "somewhere in the neighbourhood of Central America", and that "all three branches, Lemurs, Tarsioids, and Monkeys, wandered across from the New World to the Old, across bridges which stretched from North America to Africa and Europe, and also from North America to Eastern Asia". He further asserts that "before the beginning of the Tertiary period members of the Lemuroidea and Tarsioidea were living in North America," though fossils are still lacking to justify this statement. The palaeontological record is, indeed, tantalizing in its imperfection, and in no direction more so than in that of the mammals most nearly akin to man.

Both from the few known fossils and from other considerations, Professor Elliot Smith infers that the earliest members of the human family must have been merely apes with an overgrown brain. Probably the first bodily change which occurred was the modification of the legs for the new method of progression, and this was in the main the outcome of the higher development of the brain. The hand was then liberated to become the chief instrument of man's further progress. All the speculations are fascinating, and it behoves geologists and palaeontologists to take advantage of every opportunity of obtaining and preserving the rare fossils which are so much needed to place our knowledge on a secure foundation. A. S. W.

THE GEOLOGY OF WESTERN SAMOA. By J. ALLAN THOMSON. New Zealand Journ. Sci. Techn., Vol. IV, 1921, pp. 49–66.

THIS paper, partly based on original observation and partly on collation of the literature, gives a résumé of the geology of the western half of this island group, formerly a German colony, now

administered by New Zealand. The rocks are mainly volcanic, the only other type hitherto observed being coral-reefs. Within historic times there have been three eruptive phases, the last being the eruption of Matavanu (1905–11), so well described by the late Dr. Tempest Anderson. Some notes are given concerning the present condition of the lavas of this episode, especially the remarkable tunnels through which most of the flows escaped.

A list is given of all the rock-types hitherto observed in the Samoan islands: as might be expected basalt is dominant, especially olivine-basalt. Limburgite has also been known for some time, but more recent investigations, mainly by German geologists, have revealed the presence of alkaline differentiation-products, such as nepheline-basalt, nepheline-basanite, trachydolerite, trachyte, and phonolite. A comparison is made with the petrography of Hawaii. A short discussion is given of the tectonic relationships of the island group, and the paper concludes with a useful bibliography, mainly of German memoirs.

ONTARIO GOLD DEPOSITS: THEIR CHARACTER, DISTRIBUTION, AND PRODUCTIVENESS. By P. E. HOPKINS. Ann. Rep. Ontario Dept. of Mines, Vol. XXX, Part II, 1921. Second edition, 1924. pp. 73, with 27 figures (not numbered).

SINCE Ontario is now one of the great gold-producing areas of the world, the total production up to the end of 1923 having been $128,873,903, it is useful to have in a condensed form a general and comprehensive account of the mines of the Province, from the standpoint of geology and technical development, such as is provided in this well-written and well-illustrated memoir. All the gold of Ontario comes from Pre-Cambrian formations, and it may be serviceable to reproduce here the geological classification now employed by the Department of Mines: it is as follows (slightly condensed):—

KEWEENAWAN—Deposits of silver, cobalt, nickel, and arsenic at Cobalt, copper and nickel at Sudbury, following basic intrusions; gold not important.

ANIMIKEAN—Epoch of chemical iron-formation, and Cobalt series of sediments.

MATACHEWAN—Diabase dykes at Gowganda and Matachewan.

ALGOMAN—Gold at Porcupine and many other places, also auriferous mispickel and later deposits of galena, zinc-blende, fluorite, etc., following great granitic intrusions.

HAILEYBURIAN—Basic intrusions of post-Timiskamian age, with nickel, magnetite, chromite, and possibly gold.

TIMISKAMIAN—Conglomerates and other sediments, with unimportant iron formation.

LAURENTIAN—Granite intrusions; ore-deposits, if any, removed by later denudation.

LOGANIAN { Grenville—Extensive iron formation, with limestone and other sediments.
Keewatin—Mainly basic lava-flows, now largely schistose.

Of the gold-producing areas, by far the most important is Porcupine, its total production having been $113,651,229, about nine-tenths of the total output of the Province, as quoted above. The largest producer

is the Hollinger Consolidated, which is one of the great gold mines of the world, while the adjoining McIntyre-Porcupine and the Dome, 3 miles to the south-east, are also of great importance. The gold occurs in quartz veins in Keewatin volcanic schists in the Hollinger area, and in Keewatin volcanics and Timiskamian greywacke-conglomerate at the Dome, in both cases near the contact of an Algoman quartz-porphyry, now schistose. A. G. Burrows does not consider that the quartz-porphyries are directly responsible for the gold, but W. G. Miller regards the quartz-veins as genetically related to the Algoman granites.

Among the other gold-producing areas, too numerous to name individually, Kirkland Lake is probably the best known. Here the mines are situated along a fault-zone 2½ miles in length with numerous ore-shoots of varying grade, mostly composite lode-deposits of gold-telluride type with much pyrite. The fracture zone traverses various rocks, including Timiskamian sediment, Algoman syenite, porphyry, and lamprophyre, the gold being probaby derived from the differentiated intrusive magma. The Tough-Oakes has been a large producer.

In considering the mineral value of Ontario as a whole, it must not be forgotten that this Province includes Sudbury and Cobalt, with their enormous production of copper, silver, nickel, cobalt, and arsenic, both of which are among the leading mining districts of the world, in addition to a vast number of minor propositions of all kinds, and there can be little doubt that much still remains to be discovered. It is clear that here what is needed is scientific prospecting, and the general recognition of the close connexion between igneous intrusion and ore-deposit is obviously the foundation of such prospecting. In Canada as a whole there must be much scope for scientifically, especially petrologically, trained explorers, not necessarily microscopical petrographers, but men with a good acquaintance with igneous rocks in the field : it is here that academic and museum training often fails, since students are rarely allowed to see weathered or decomposed specimens of the rocks they study, and therefore cannot link up what they see in the field with the cabinet specimens of the museum. In Canada, owing to the intense glaciation, it is easier to get fresh rock than in most places : in many tropical regions it is almost hopeless.

R. H. R.

Geological Survey of Nigeria : "The Phosphate Deposits of Abeokuta Province." By W. Russ, with Note by C. W. Andrews. Bull. No. 7, pp. 43, one plate of Geol. Sections, one Map, pls. i–vi.

THESE deposits are situated on either side of the Lagos Government Railway, about midway between that town and Abeokuta. A homogeneous clay partly encloses the phosphate beds and contains gypsum and aragonite, representing deposition in a lagoon or series of lagoons, while the phosphates are believed to be the result of

incursions of the sea (most marked during the time when a granular variety was deposited), their origin being attributed to the decomposition of the various members of the marine fauna. Lagoon and shallow water conditions, during which clays and coarse grits were laid down, followed. The beds are of Eocene age. Five types of phosphate are described, of which two are merely the altered representatives of two principal varieties, i.e. granular and nodular. These altered rocks are characterized by phosphoric anhydride. The fifth variety is represented by concretionary aggregates. The granular type, composed of grains of calcium phosphate about 1 mm. in diameter, contains also minute molluscan casts, fragments of echinoids, and crustacea, bones of fish and reptiles, foraminifera and coprolites. The nodular (" normal ") type, a coarse facies of the granular, has similar composition but contains an excess of phosphoric anhydride over the amount required to form calcium phosphate with the available quantity of lime. This excess is combined with alumina as wavellite. Passing over the descriptions of the five sub-areas into which the known occurrences of phosphate are divided, a section of the Report gives a number of analyses with an estimate in two cases of the quantity and richness of the material available, when the overburden is thin. In these two localities the latter is only 2 and 3 feet thick respectively, and the author estimates that strips of country, having lengths in the one of 1 mile and in the other of $1\frac{1}{2}$ miles and both 200 feet wide, would yield in the first instance (average thickness 2 ft.) 60,000 tons with an average content of 60 per cent $Ca_3P_2O_8$, and in the second (average thickness 1 ft.) 30,000 tons with 29·6 per cent of the anhydride.

The " Appendix " by the late Dr. Andrews describes, with two text-figures, three vertebrae of a new snake, probably marine and referable to the English genus *Palaeophis*. From the characters of these bones he deduces that the beds are probably earlier than the London Clay.

The discovery of these deposits appears to have been largely due to the construction of a diversion of the railway which exposed the beds in cuttings, the original line missing the phosphates altogether. It is an instance of the ease with which valuable information can be passed by in the dense vegetation of Southern Nigeria. The plates of the phosphate deposits and the photomicrographs (by Mr. Sweeting) are admirable. Mr. Russ is to be congratulated on a complete and careful piece of work.

J. P.

BULLETIN OF THE GEOLOGICAL SOCIETY OF CHINA. Vol. II, Nos. 3–4, pp. 118, 3 plates, and 20 figs. Peking, 1923.

BESIDES abstracts of the proceedings at the sixth general meeting of the Society, 15th June, 1923, with titles of several papers promising to be of considerable interest when published in full, this publication contains two long memoirs of some forty-five pages

each, entitled "L'influence séismogénique de certaines structures géologiques", by W. H. Wong, and "A graphic method to aid specific determination of Fusulinoids and some results of its application to the Fusulinae from N. China", by J. S. Lee. There is also a note, with a plate of sections, on the first meteoric stone received by the Geological Survey of China, by C. Y. Hsieh. The seventh meeting was mainly occupied by reports of the results of the Third Asiatic Expedition, by H. F. Osborn, Roy C. Andrews, and W. Granger. A special meeting was also held to welcome Dr. Sven Hedin, who gave an address outlining his journeyings in Asia and their results.

OBITUARY.

Robert Kidston, LL.D., D.Sc., F.R.S., F.R.S.E., F.G.S.

BORN 28TH JUNE, 1852. DIED 13TH JULY, 1924.

The news of the death of Robert Kidston was received with a feeling almost of incredulity; though no longer young in years, he retained in a remarkable degree the enthusiasm and, apparently, the vigour of youth. He died at Gilfach Goch in South Wales, where he had gone to work with his friend Mr. Davies at a collection of Carboniferous plants. His end came with suddenness; such an end as he would have wished—in the midst of work. He leaves a widow and two daughters.

From the time when Kidston deliberately gave up the prospects of a business career to follow the compelling call of scientific research he devoted the greater part of his amazing energy to the study of Carboniferous floras. It was fortunate for science that he was able to take up the unremunerative occupation of original investigation. In early days he held for a time the post of Demonstrator in the botanical department of Edinburgh University, but most of his life was, one may almost say, consecrated to research. By extraordinary industry, by combining the enthusiasm of a collector with the scientific insight of a student, he acquired a systematic knowledge of Carboniferous plants which has never been surpassed. For many years Kidston has been recognized by his co-workers both at home and abroad as a master and authority to whom appeals were made with confidence, because he was not only exceptionally well informed on his own branch of Palaeobotany, but always direct and sincere in his criticisms, and ever ready to help others. Many younger men have special cause to remember with gratitude his kindness and his treatment of them as equals. It is often said that a man has limitations; who has not? The important point is that many men do not realize their limitations, and act accordingly. Kidston was transparently honest with himself as with his fellow workers; though on occasion dogmatic he was always open to conviction. It was a pleasure and an education to argue with him. His services to science, both pure and applied, though fully appreciated by his colleagues, have not been as fully recognized officially as they merited. He was

elected a Fellow of the Royal Society in London in 1902; in 1916 the Geological Society awarded him the Murchison medal, and from the University of Glasgow he received the Honorary Degree of LL.D.

The earliest paper by him in my possession was published in 1882; the last, in collaboration with Professor Lang, of Manchester, in 1923. For more than forty years he consistently devoted himself to the intensive study of the later Palaeozoic floras; he demonstrated, as no other British Palaeobotanist has done, the value of fossil plants as guides to geological chronology; he acquired a wonderful knowledge of specific characters, and formed a collection of Carboniferous plants which is probably unsurpassed in quality.

After publishing a large number of papers on the macroscopic characters of Carboniferous species and on the vegetation of several coal-fields, he turned his attention to anatomical studies. In order thoroughly to qualify himself for this new line of research he attended laboratory courses at the University of Glasgow, under his friend Professor Bower. One result of this was a partnership with the late Professor Gwynne-Vaughan, which led to a valuable series of papers on fossil Osmundaceae and on many other types of extinct plants. After the premature death of the junior author, for whom Kidston felt a very warm affection, he was joined by Professor Lang, and to this very happy union we owe the most important contributions which have ever been made to our knowledge of the plants of the Devonian period.

Kidston was an expert photographer and draughtsman, and the value of his memoirs is enhanced by the excellence of the illustrations prepared by himself. With a retentive memory and a remarkable grasp of his subject, he combined a capacity for taking infinite pains and a passion for orderliness and method which excited the amusement and the envy of friends. From first to last he concentrated attention on Palaeozoic floras, and worked in close co-operation with the Geological Survey. To him more than to any other man the Survey is indebted. Since the days of Sir Joseph Hooker's short connexion with that Government Department, the official Staff has not included a Palaeobotanist; but Kidston's knowledge was always at the disposal of the Director and was freely used. In his earliest papers he described specimens sent to him by the officers of the Geological Survey of Scotland, and at the time of his death he was engaged in the preparation of a Memoir on the Carboniferous floras which was to be completed in ten parts; four of these have been published. I have previously contributed to the GEOLOGICAL MAGAZINE a short account of this truly great work; it is with profound regret that one must now refer to it as a memorial left unfinished by him whose life-work it would have represented. I venture to express the hope that a way will be found of making an attempt to complete the great undertaking; there is no doubt much material prepared by the author, and there is certainly the stimulus of loyal devotion to his memory.

The recollection of days spent with Kidston in his home at Stirling is a precious possession. He was a true friend, generous and unchanging, a student; and intensely human: unequalled in his knowledge of plants which grew in an era inconceivably remote, he cared equally for the plants which he cultivated with conspicuous success in his own garden. The loss of him is hard to bear because he was one who inspired affection as well as respect; the memory of what he did for others and the sacrifices he made for the advancement of knowledge will long remain, but the written record of his work will endure still longer.

A. C. Seward.

Charles William Andrews.

Born 1866. Died 25th May, 1924.

Geologists and palaeontologists regret the premature death of Dr. C. W. Andrews, who has added so much to our knowledge of fossil vertebrates during the past thirty years. It was known to his friends that he had long been afflicted with a lingering illness, which he had borne with great fortitude; but he eagerly pursued his researches without intermission, and his end came peacefully in the midst of work.

Dr. Andrews was born at Hampstead in 1866, and graduated in both science and arts in the University of London. He began his career as a schoolmaster, but in 1892 he competed for and obtained a vacant assistantship in the Department of Geology in the British Museum (Natural History). He now had ample opportunities for following his bent in natural science, and he achieved so much success in original research that he attained the London degree of D.Sc. in 1900.

When Dr. Andrews joined the staff of the British Museum, he was first entrusted with the curating of the fossil birds. Here he soon found new material, and like most British geologists of the last sixty years he began his career as a contributor to our science in the Geological Magazine. His first paper, published in 1894, described the remains of the largest known ratite bird from Madagascar, which he named *Aepyornis titan*. Although as an assistant curator he soon had to deal with all the higher vertebrates, he retained a special interest in birds to the end, and he wrote several valuable papers on the extinct birds of New Zealand, the Chatham Islands, and Patagonia, besides a notable account of a primitive tropic-bird (*Prophaethon shrubsolei*) from the London Clay of Sheppey.

Encouraged by the discoveries of Mr. Alfred N. Leeds in the Oxford Clay of Peterborough, Dr. Andrews also began early to take a special interest in the marine reptiles of the Jurassic period. In 1895 he described the growth-stages in the shoulder-girdle of a Plesiosaur, and in later years he made many contributions to our knowledge of the skull and other parts of the skeleton of the Sauropterygia, Ichthyopterygia, and Crocodilia. His results were summarized in the exhaustive *Descriptive Catalogue of the Marine Reptiles of the Oxford Clay,*